GUIDEBOOK NO. 16

QUATERNARY GEOLOGY ALONG THE EASTERN MARGIN OF THE SCIOTO LOBE IN CENTRAL OHIO

by

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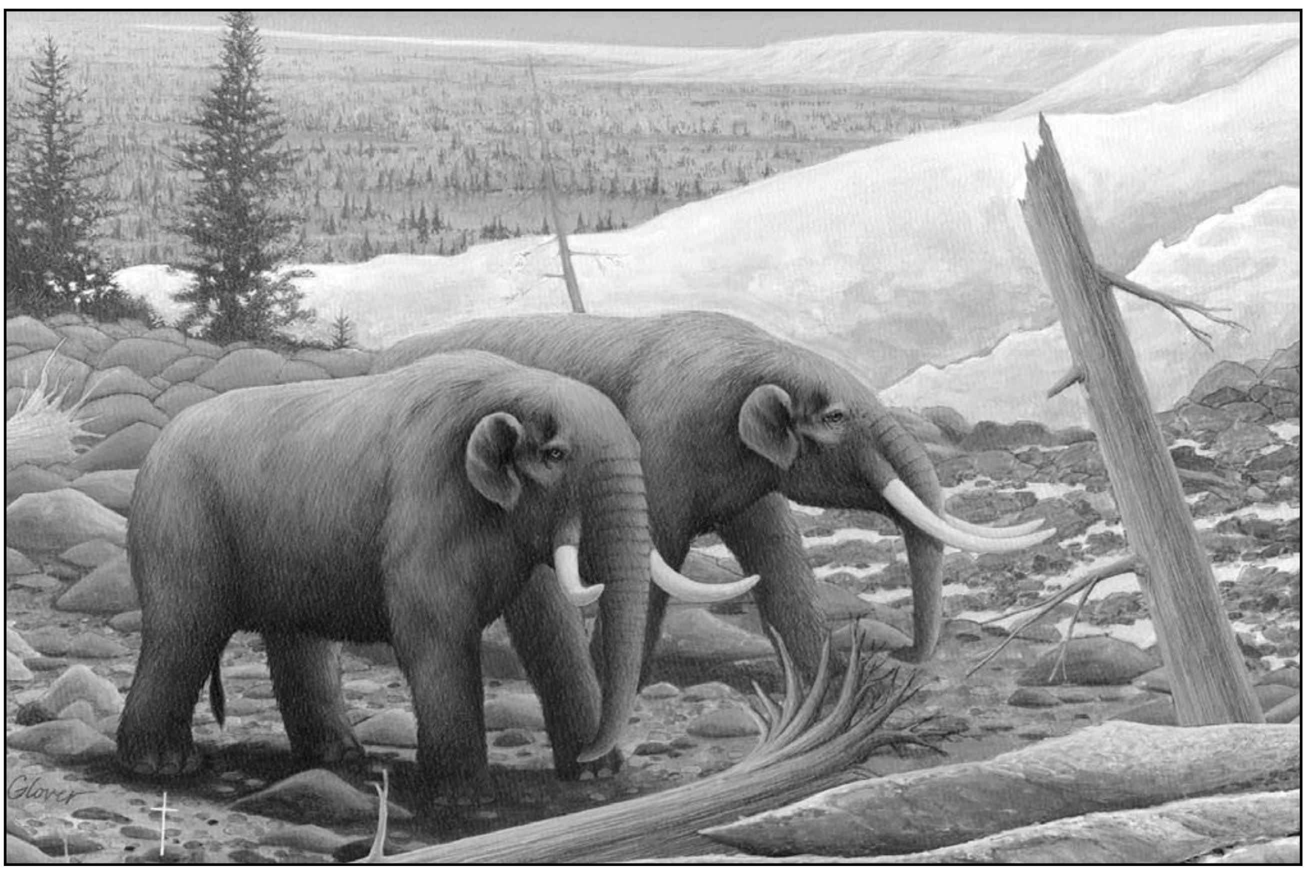

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Composition and layout by Lisa Van Doren

This guidebook has been edited by the Ohio Division of Geological Survey, but has not been reviewed for scientific content. The views and interpretations expressed are those of the authors. The Division of Geological Survey disclaims any responsibility for interpretations and conclusions.

Cover illustration: Mastodons along the ice margin. From a painting by James L. Glover, Ohio Department of Natural Resources.

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PREFACE

This field guide is a joint effort of its authors (Frolking and Szabo). Our research in the area, however, has been largely independent. Szabo has had a long-standing interest in the glacial stratigraphy of northeastern and central Ohio; Frolking's interest centers on landscape evolution integrating hill-slope, fluvial, and glacial activity. We both have a strong interest in the impact of Pleistocene glaciations on the margins of the Allegheny Plateau. Our different backgrounds, research interests, and perspectives, although often mutually enriching, can lead to different interpretations of data and the implications for the stratigraphy and geomorphic history of the area. We both have "lumping" and "splitting" tendencies, the latter naturally linked to our areas of expertise. We have attempted to indicate where the interpretations or conclusions expressed are those of only one of the authors. Many sections were written by a single author and in those cases the author is indicated.

This guidebook was prepared for an authors-led field trip in conjunction with the 1998 North-Central Section meeting of the Geological Society of America. Subsequent users of this guidebook must obtain permission of the landowner to visit any of these sites that are on private property.

Please note: metric units are used throughout this guidebook. However, map/road distances are given in English units, followed by the metric equivalent in parentheses. Elevations are given in meters, followed by English equivalents in parentheses.

QUATERNARY GEOLOGY ALONG THE EASTERN MARGIN OF THE SCIOTO LOBE IN CENTRAL OHIO

by Tod A. Frolking
and John P. Szabo

PART 1: INTRODUCTION

OVERVIEW OF FIELD TRIP AND EARLY RESEARCH IN THE AREA

This field trip will examine the terrain and the Pleistocene deposits on a general west-to-east transect from Columbus, near the center of the late Wisconsinan Scioto lobe, to Black Hand Gorge, at the eastern margin of the Illinoian advance in eastern Licking County (fig. 1).

Licking County is situated within the drifted area of Ohio and almost entirely within the outcrop of the Waverly Group of the Sub-carboniferous rock system . . . . The topography is made up of three elements. First: The original preglacial topography produced upon the monoclinal rock structure of the Waverly by preglacial erosion. Second: The changes produced by the depositions of the glacial period. (Including moraines, terraces and all accompanying actions.) Third: The effects of erosion since glacial time. The combination of these three elements gives a varied and pleasing landscape but one offering many perplexing problems of Quaternary geology."

W. G. Tight (1894b, p. 17)

We make this trip about one century after a period of very productive geomorphologic research in the area. Several major publications from that period have served as a framework for much subsequent work in Licking County, in Ohio, and in much of the Great Lakes and upper Ohio Basin area. William George Tight was a Denison student (class of 1886) and then a Denison professor from 1887 to 1900 before moving to New Mexico. His 1894 paper (Tight, 1894a) in the Bulletin of the Scientific Laboratories of Denison University examined glacially induced changes in the Licking and Muskingum River systems and gave some attention to other basins in Ohio. Tight went on to synthesize research on drainage changes in much of the middle Ohio Basin, focusing on the Teays River system, in his classic 1903 U.S. Geological Survey Professional Paper. In subsequent years, Denison students and professors, including Brian Clark, Frank Carney, and Kirtley Mather, followed Tight's lead and published works on various aspects of the area's glacial geology and drainage evolution (see Clark, 1902; Carney, 1907a, 1907b; Mather, 1908).

Lacking specific age controls, Tight made no attempt to assess the timing of the drainage changes he described. More detailed subsequent work in Licking County would depend on Frank Leverett's (1902) comprehensive synthesis of glacial terrain and drainage patterns of the Erie and Ohio Basins. His interpretations of Illinoian and Wisconsinan glacial terrain have stood the test of time. Since then, many noteworthy scientists have added countless details to Tight's and Leverett's pioneering works. Many of their contributions are reviewed herein. Let this trip be a centennial celebration of the pioneering work of William Tight and Frank Leverett. We hope we can learn something new in the "varied and pleasing landscapes" along the glacial margin in east-central Ohio.

REGIONAL BEDROCK STRATIGRAPHY AND THE MODERN TERRAIN

Mississippian and lower Pennsylvanian bedrock strata (fig. 2) of eastern Franklin and Licking Counties dip generally eastward into the Appalachian Basin at about 30 feet/mile (5 meters/km). As we head eastward, rocks of progressively younger age crop out, from the Bedford Shale, which is exposed along Rocky Fork (Stop 1), to the Logan Formation, which caps ridges of central Licking County (Bork and Malcuit, 1979). Pennsylvanian rocks of the Pottsville Group mantle uplands to the south and east of Stop 7 and form the ridges of much of easternmost Licking County (DeLong, 1972).

The field-trip area lies on the border between the Allegheny Plateau physiographic province to the east and the glacial till plains of the Interior Lowlands province to the west (Brockman, 1998). The preglacial topography, and to a large extent the modern topography, consist of a series of north-south-trending, eastward-dipping, dissected cuestas. The resistant units that form the bedrock highs typically have a thin drift mantle. The Berea Sandstone in eastern Franklin County forms a fairly linear north-south-trending topographic high (Krissek and Coats, 1995) which has had a strong impact on the margin of the Scioto lobe (Fernandez and others, 1988).

In Licking County, the Black Hand and Raccoon Members in the upper part of the Cuyahoga Formation exhibit a facies change from coarse sandstone and conglomerate in eastern Licking County to siltstone in the west (Bork and Malcuit, 1979). Sheetlike units of the overlying Logan Formation consist of the thin, conglomeratic Berne Sandstone Member, the Byer Sandstone Member, the conglomeratic Allensville Sandstone Member, and the variable sandstones, siltstones, and shales of the Vinton Member. In eastern Licking County, a thicker component of resistant, coarse, clastic units, perhaps augmented by paleodrainage to the southwest, has resulted in generally higher bedrock-surface elevations than in the western portion of the county (fig. 3). Comparably thick glacial deposits in western Licking County, however, have masked this relationship. The till plains, particularly in northwestern Licking County, are actually equal to or higher in elevation than the ridge crests of the unglaciated Allegheny Plateau in the eastern townships. The notable increase in relief toward the east is due principally to the descent of valley floors eastward in keeping with the modern drainage.

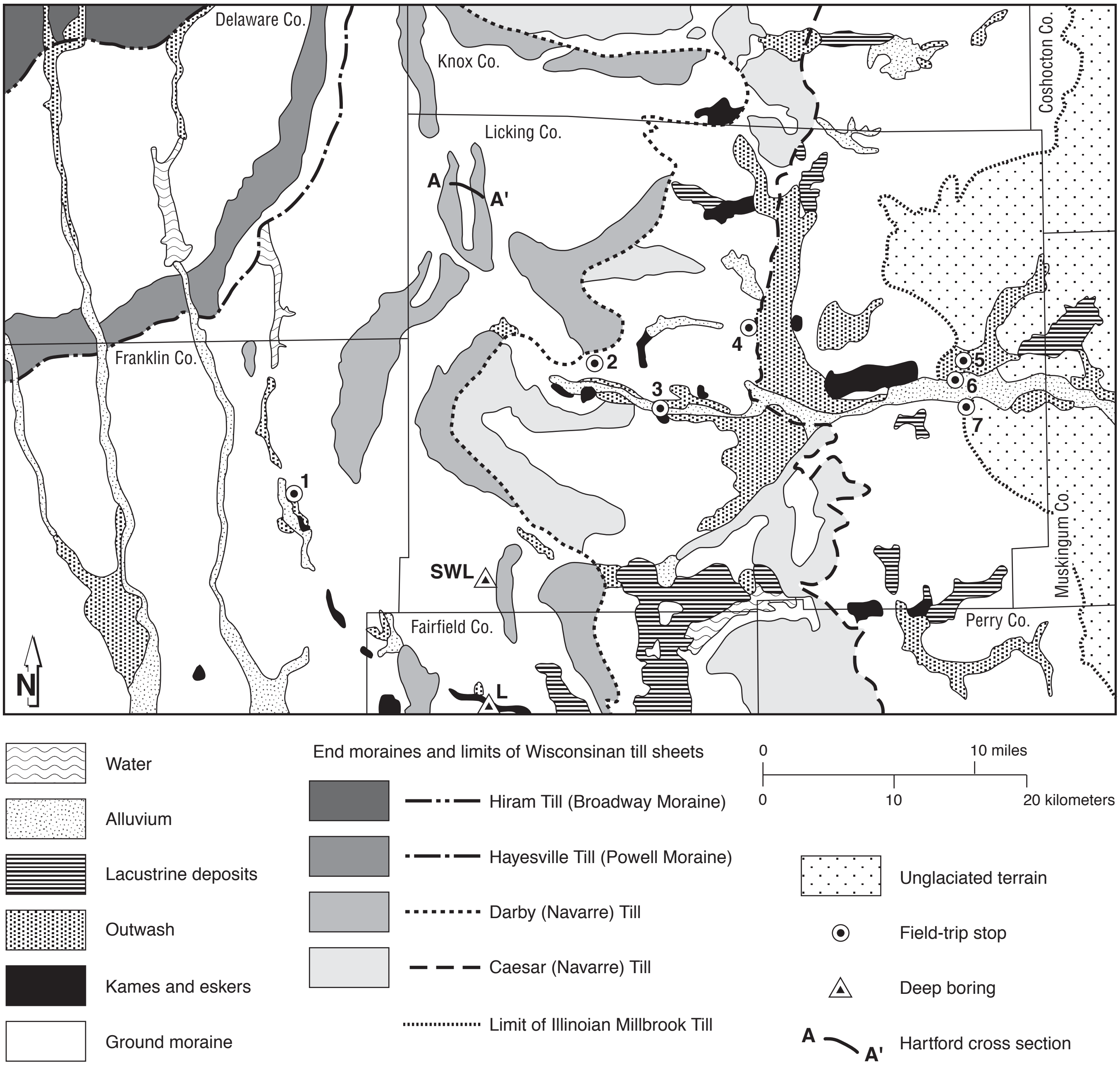

FIGURE 1.—Generalized Quaternary geology of the field-trip area in east-central Ohio showing locations of stops (modified from Goldthwait and Pavey, 1993, and Goldthwait and Van Horn, 1993). Locations of two deep borings also shown; **L** = Lancaster; **SWL** = southwest Licking County. See figure 9 for stratigraphy of Hartford cross section (A-A').

PALEODRAINAGE HISTORY

Most researchers who have studied paleodrainage in central Ohio focus on two drainage phases, the Teays and the Deep Stage (Stout and others, 1943; Coffey, 1958). The Teays drainage, which historically has been assigned to the Tertiary (Goldthwait, 1991), is now considered by many to incorporate one to several phases of early to middle Pleistocene glacial diversions in central Ohio, Indiana, and Illinois (Melhorn and Kempton, 1991). The subsequent phase of valley incision leading to the Deep Stage resulted from significant glacial drainage diversions and perhaps an extended period of low sea level. The diversion of the main Teays system, which drained westward across central Ohio and Indiana, to a more direct route down the newly formed Ohio River may be a principal cause of the Deep Stage incision (Teller and Goldthwait, 1991). In southwestern Ohio, the Deep Stage valley floors lie about 75 meters below the Teays-age valleys and more than 30 meters below the modern Ohio River floodplain.

In central Ohio, one interpretation of the drainage history suggests that the Teays-age Groveport River flowed south through central Knox and Licking Counties, was joined by the westward-flowing Cambridge River at New-

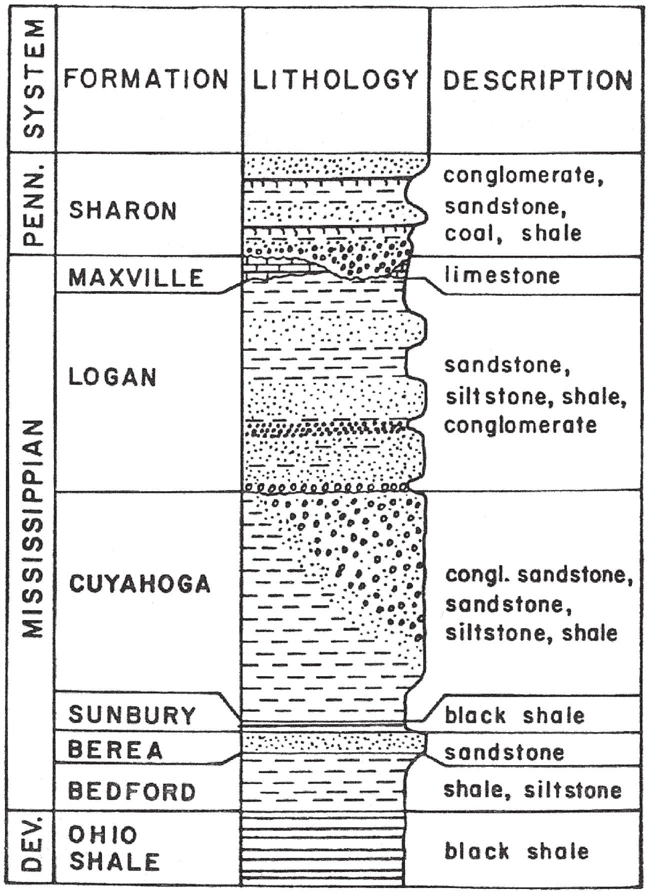

FIGURE 2.—Generalized geologic column for upper Devonian through lower Pennsylvanian rock units in central Ohio (from Bork and Malcuit, 1983).

ark, and then continued southwestward through this valley into southeastern Franklin County (Stout and others, 1943). Differing from this earlier interpretation, Dove (1960) placed the Groveport River in a now-buried north-south valley in western Licking County. He suggested that the southward path of this river was blocked and diverted at Utica to form the Utica River during the development of the Deep Stage system (fig. 4).

The Deep Stage Newark River, analogous in Licking County to the Teays-age Cambridge River, was the major river draining east-central Ohio (fig. 4). On the basis of well logs, Dove (1960) estimated that the Newark River incised 20 to 25 meters below the Teays-age Groveport-Cambridge River drainage. At this time of high relief, the valley floor of the Newark River lay as much as 180+ meters below the adjacent ridge tops (fig. 5A). Well-log density is insufficient to characterize the morphology of the bedrock valley floor, which could help constrain the duration of the Deep Stage.

DRAINAGE DIVERSIONS AND REVERSALS

Forsyth (1966) identified numerous breached drainage divides in the central and particularly the eastern portions of Licking County. For the most part, diversions occurred as westward drainages were blocked by eastward-advancing ice. Some diversions may have been cut by subglacial meltwater, but because of thin upland ice along the Allegheny Plateau margin, such diversions are probably less likely than in ice-marginal areas farther north, as, for example, in south-central Wisconsin, the location of the 1997 North-Central Section GSA field trip (Clayton and others, 1997). The most significant drainage diversion in the region formed the modern Muskingum River by the breaching of the divide at McConnelsville in Morgan County (fig. 4) (Tight, 1894a). The blockage of the ancestral Newark River near Hanover in Licking County and the subsequent breaching of a divide

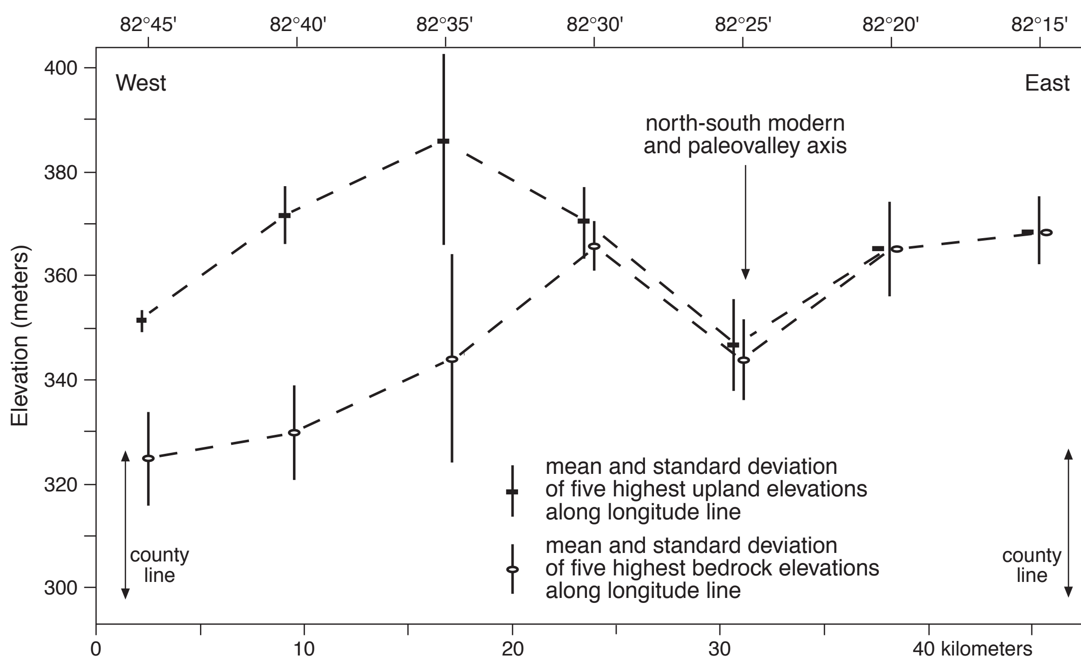

FIGURE 3.—Mean and standard deviation of five highest bedrock and land-surface elevations taken from 1-minute latitude increments along successive 5-minute longitude lines across Licking County. Bedrock elevations in western Licking County were estimated from maps by Dove (1960) and Forsyth (1966) and water-well data. Vertical exaggeration 250:1.

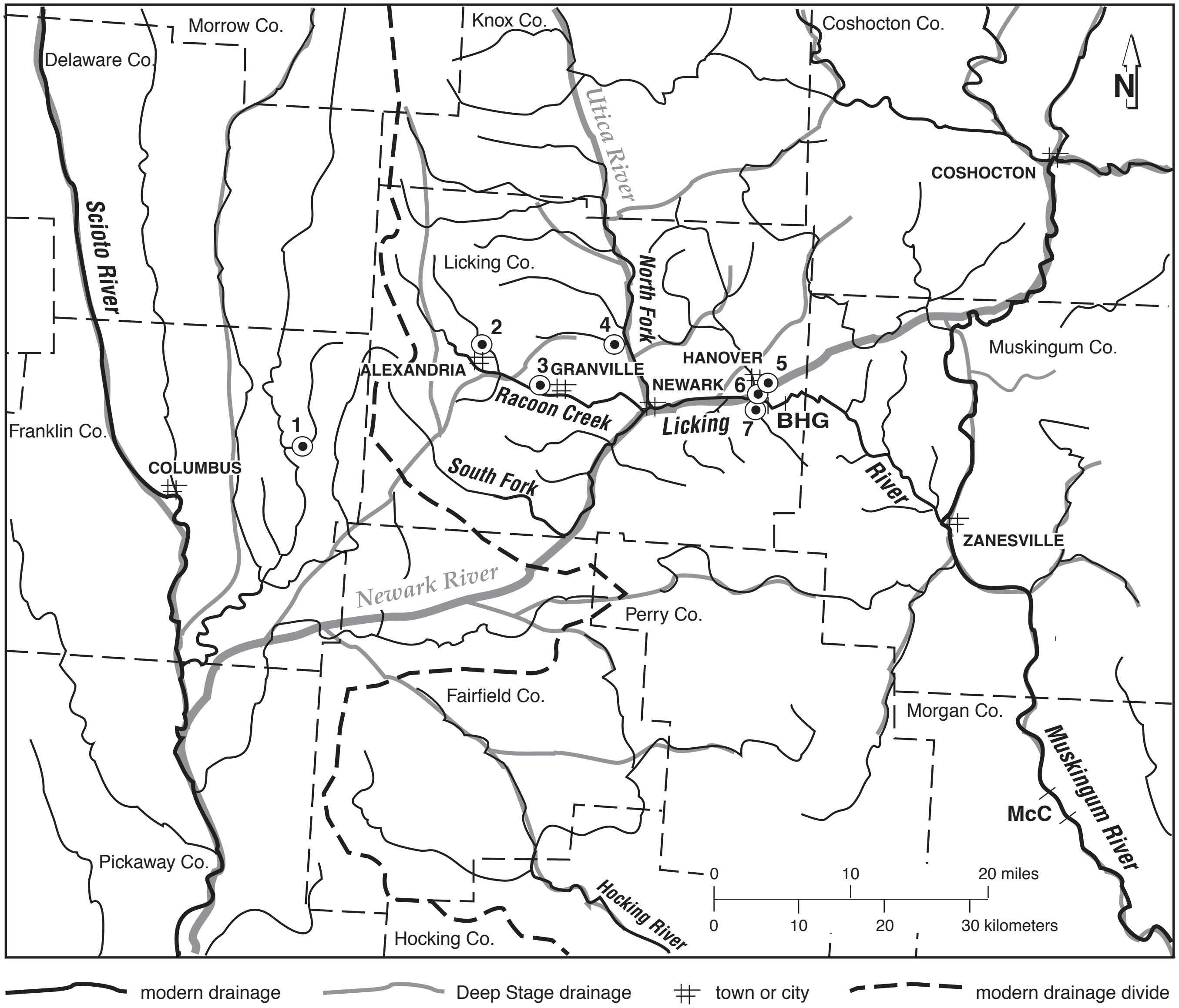

FIGURE 4.—Map showing the modern and Deep Stage drainage patterns for east-central Ohio. Deep Stage rivers from Dove (1960). **BHG** = Black Hand Gorge; **McC** = breached divide at McConnelsville. Stop locations also indicated.

to the southeast leading to development of the eastward-flowing Licking River is a major focus of this field trip (fig.4; Stops 4, 5, and 6). The road log (Part 2) and stop discussions (Part 3) provide more details.

MIDDLE AND LATE PLEISTOCENE VALLEY FILLS

Since the Deep Stage incision, landscapes of Licking County have been modified principally by the filling of valleys with fine-grained till, lacustrine sediment, and outwash. Along the axis of the ancestral Newark valley in south-central Licking County, middle to late Pleistocene valley fill is 105-120 meters thick (fig. 5B). In general, valley-fill composition depends strongly on drainage direction relative to the advancing ice fronts (Frolking, 1997). As glacial ice of the Scioto lobe advanced from the west, westward drainages were progressively blocked at different outlet points, forming proglacial lakes of varying extent and duration that were filled with fine-textured proglacial lacustrine deposits. Coarse outwash deposits are limited in these impounded valley environments, commonly being present only as localized kame-terrace and delta-kame deposits such as those on the north side of the Deep Stage Newark valley east of Newark (Forsyth, 1966). In the South Fork Licking River valley (fig. 4), most water-well drillers' logs reveal a preponderance of fine-grained sediments (75 to 85 percent silty diamicton and lacustrine silt/clay in the upper 30 to 40 meters). In contrast, the North Fork Licking River valley contains considerably more outwash sand and gravel in the upper 40 meters (Angle and others, 1993). This valley has drained southward since Teays time, allowing for relatively free drainage and the fluvial transport of some fine sediment out of the valley as glacial ice wasted.

The deepest Pleistocene deposits that have been studied in Licking County are from a 100-meter-deep test boring in a buried valley in the southwestern part of the county (fig. 1). This core was acquired from an engineering firm through the efforts of consulting geologist Julie Weatherington-Rice,

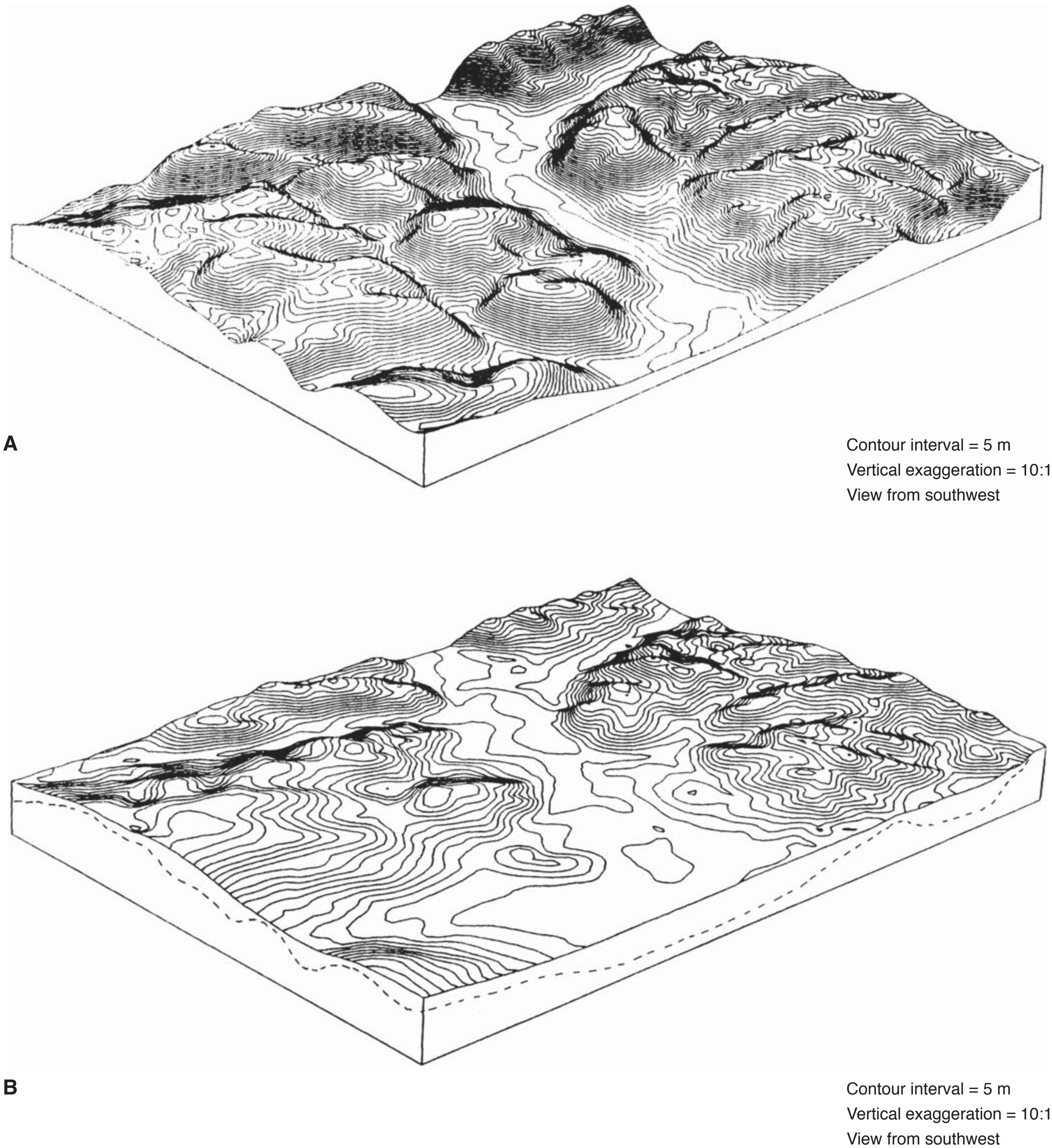

FIGURE 5.—Generalized bedrock (A) and land-surface (B) elevation models of south-central Licking County as viewed from the southwest. Figure dimensions are 11.8 miles (19 km) north-south and 16.8 miles (27 km) east-west. Raster-based models developed from 500-meter grid spacing of elevation data. Bedrock elevations were estimated from maps by Dove (1960) and Forsyth (1966) and water-well data.

and samples were analyzed by Szabo. Firm, calcareous, laminated, grayish-brown silty clay is present in the lower 8 meters of the boring and is overlain by about 12 meters of very firm, calcareous, yellowish-brown sandy silt. These low-conductivity deposits resemble a stack of "checkers" when they are extracted from the sampler (Julie Weatherington-Rice, personal commun.). Ira Sasowsky of the University of Akron analyzed the paleomagnetic signatures of eight samples from these sections. Three samples had reversed polarities and five had normal polarities. Unfortunately, the orientations of some of the cores are uncertain. Thus, it remains unclear whether these deposits are correlative with the Minford Silt, which is magnetically reversed and hence older than 730,000 years (Fullerton, 1986). Most likely the deposits postdate the Minford Silt and the Deep Stage incision.

Very firm, calcareous, massive, matrix-supported, light-gray to gray diamictons dominate between 10 and 81 meters (fig. 6). Some diamictons are separated by sand and gravel units a few meters thick which serve as aquifers for individual wells in the area. The other breaks between diamictons in figure 6 are based on changes in texture or carbonate content. The two very firm calcareous diamictons from 55 to 81 meters show slight changes in texture and fine-carbonate content and cannot be correlated with any known tills cropping out at the surface. These diamictons could be Illinoian in age or older. The diamictons between 35.5 and 55 meters have carbonate contents similar to the Chesterville Till, and the diamictons between 10 and 35.5 meters have carbonate contents similar to the Gahanna Till; thus, they are assigned by Szabo to the Illinoian glaciation (see section below on till nomenclature). The upper loose to firm, calcareous, massive, matrix-supported, brown diamicton (0 to 6 meters) was cored using a Giddings soil probe. It is not known if there is a Sangamonian weathered zone in the 4 meters of uncored material below this Wisconsinan unit, but there was a significant change in consistency below that depth. On the basis of tentative correlations, 90 to 95 percent of the material in this boring may be Illinoian or older.

Szabo analyzed samples from another boring obtained by Julie Weatherington-Rice from a buried valley northwest of Lancaster in Fairfield County about 8 miles (13 km) south of the boring in southwestern Licking County (fig. 1). This boring was also 100 meters deep, but the lower 45 meters were bored using the mud-rotary method, which contaminated the lower section with smectitic clay. The stratigraphy of this zone was interpreted from geophysical logs (fig. 7). The deepest reliable samples (50.5 to 56 meters) are from a very firm, laminated, calcareous silty clay that coarsens downward. The upper section in this hole consists of friable to firm, blocky to platy, calcareous, massive, matrix-supported, gray to light-gray diamictons separated by laminated or massive grayish-brown fines and sand. Samples from this upper zone can be divided into at least four lithosequences

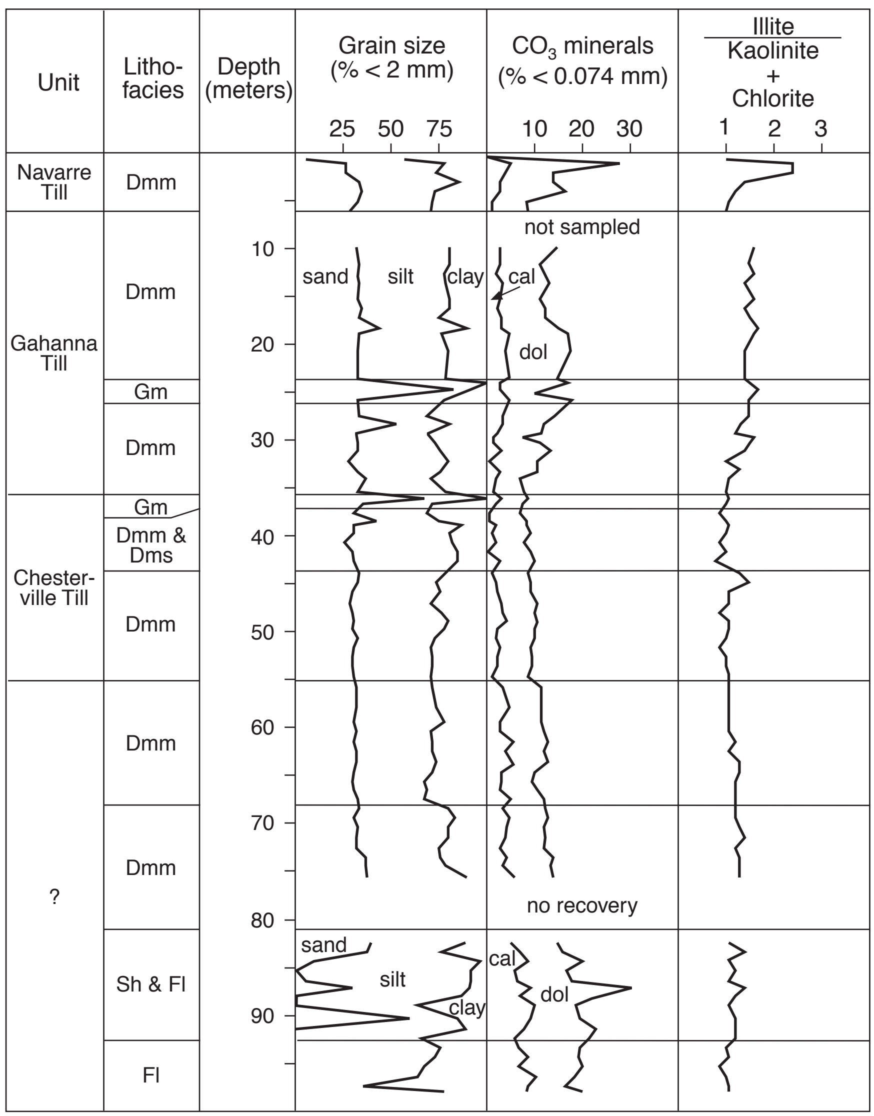

FIGURE 6.—Summary of laboratory analyses of lithofacies in the deep boring in southwestern Licking County. See figure 1 for location. The lithofacies classification code used for this and subsequent descriptions is from Eyles and others (1983). Capital letters denote sediment texture: D = diamicton, F = fines, G = gravel, S = sand. The first lower-case letter for diamictons denotes support: c = clast supported, m = matrix supported. The second lower-case letter for diamictons and the first lower-case letter for sorted materials indicate internal structures: d = soft- sediment deformation, g = graded, h = horizontal lamination, l = laminated, m = massive, r = rippled, s = stratified, t = trough cross-bedded. Lower-case letters in parentheses indicate a genetic interpretation: (c) = current reworked, (r) = resedimented, (s) = sheared. cal = calcite; dol = dolomite.

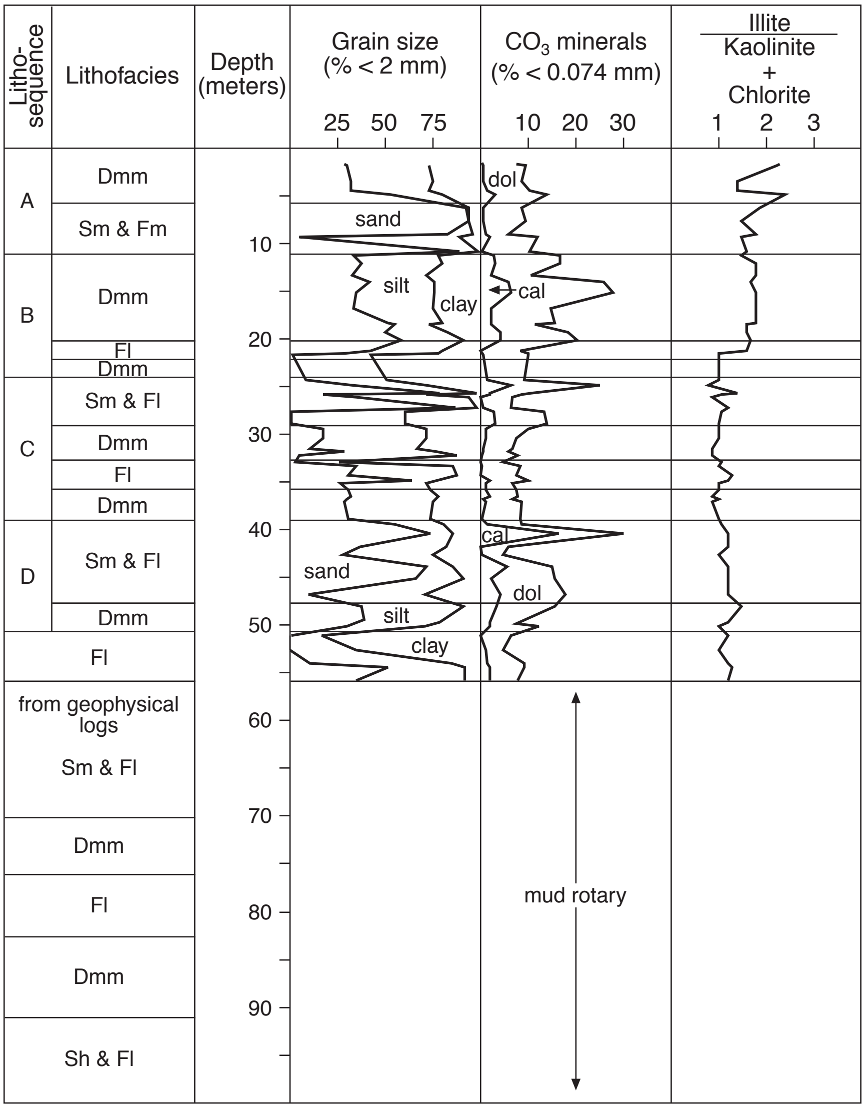

FIGURE 7.—Summary of laboratory analyses of lithofacies in the deep boring northwest of Lancaster in Fairfield County. See figure 1 for location and figure 6 for explanation of lithofacies.

using changes in texture, fine-carbonate content, and clay mineralogy (fig. 7). The oldest lithosequence, D (39 to 50.5 meters), consists of a diamicton overlain by massive sand and laminated fines. Lithosequence C (24 to 39 meters) includes two diamictons separated by laminated fines and overlain again by massive sand and laminated fines. Lithosequence B (11 to 24 meters) is similar to C but lacks the overlying sand and fines, contains more fine carbonate, and has a larger diffraction intensity (DI) ratio. The youngest lithosequence, A (2 to 11 meters), has massive sand and fines at the base overlain by a diamicton having less fine carbonate than those in lithosequence B.

The lithosequences in the Lancaster boring are similar to those described in several borings at the London Correctional Institute, 27 miles (44 km) southwest of Columbus, along the western margin of the Scioto lobe (Lloyd, 1998). The lithosequences at that location are interpreted to be late Wisconsinan in age based on a radiocarbon age of 28,390 ± 330 years before present (B.P.) (ISGS-3224) for wood from sand and gravel in a channel cut into lacustrine sediments at a depth of 74 meters. The borehole in Fairfield County is within a few kilometers of a moraine correlative with the London Moraine southwest of Columbus. The four lithosequences in the Fairfield County boring are similar to those at London and are tentatively assigned by Szabo to the late Wisconsinan glaciation.

Numerous other lines of evidence presented in this field guide will suggest substantial deposition of valley-fill materials during the late Wisconsinan. One line of evidence relevant to this discussion is the radiocarbon date of 44,130 ± 1330 years B.P. (Beta-91906) on wood from a depth of 25 meters in a diamicton just 3 meters above the bedrock surface on the north flank of the South Fork valley near Kirkersville. This site is about 6 miles (10 km) east of the deep boring in southwestern Licking County.

OVERVIEW OF REGIONAL GLACIAL HISTORY

Interpretations of central Ohio's glacial history continue to be hampered by poor dating control and uncertain stratigraphic relationships due to similar composition of successive deposits and the potential erosion of glacial deposits during subsequent glacial advances. A general lack of paleosols or weathered zones which would indicate a time lapse between deposits further hampers assessment of relative ages of units (see Szabo, 1992).

Dreimanis (1957) first proposed the tripartite division of the Wisconsinan Stage into early, middle, and late on the basis of the stratigraphic sequence in the Plum Point/Port Talbot area on Lake Erie's north shore. Exposures south of Lake Erie, including those at Garfield Heights in northern Ohio and Titusville in northwestern Pennsylvania, provided for broader correlations of glacial and interstadial deposits (see reviews by Dreimanis and Goldthwait, 1973; White, 1982; Fullerton, 1986). In central Ohio, an early Wisconsinan ice advance was thought to have deposited the Gahanna Till in southern Franklin County (Goldthwait and Rosengreen, 1969) and to have led to the formation of the intermediate-level Lancaster Outwash in the Hocking River valley to the southeast (Kempton and Goldthwait, 1959). South of the Lake Erie/Ohio River divide, researchers found no evidence of a middle Wisconsinan ice advance (Dreimanis and Goldthwait, 1973; Gooding, 1975).

More recent interpretations of late-glacial stratigraphy in northern Illinois (Kempton and others, 1985; Curry, 1989) and along the north shore of Lake Ontario near Toronto (Eyles and Westgate, 1987) suggest that early and middle Wisconsinan glacial ice did not extend southward into the southern Great Lake basins and therefore did not extend into Ohio. These findings have prompted new investigations and reinterpretations of late-glacial stratigraphy in Ohio. Szabo (1992) argues for an Illinoian age (rather than early Wisconsinan) for the Millbrook Till, which accounts for the bulk of the till deposits in north-central Ohio and controls much of the end-moraine topography (see discussion below). Unfortunately, no distinct weathering profiles in the upper part of the Millbrook Till have been found. In southwestern Ohio, Miller and others (1992) place a pre-Wisconsinan age on the Whitewater and Fairhaven tills, formerly thought to be early or middle Wisconsinan age. The 1:250,000-scale Quaternary geology of Ohio maps of the Ohio Division of Geological Survey incorporate these revisions (see Goldthwait and Pavey, 1993, and Goldthwait and Van Horn, 1993, for the maps in this series that cover the field-trip area).

CHANGING TILL NOMENCLATURE

Wisconsinan tills

Names, correlations, and age assignments of tills in the area glaciated by the Scioto lobe have undergone many revisions in the past 40 years (table 1). In his report on the ground-water resources of Licking County, Dove (1960) mentioned the existence of Illinoian till and located the Illinoian and Wisconsinan boundaries on the basis of unpublished work of George W. White on file at Ohio State University. He subdivided the Wisconsinan glacigenic sediments into three groups on the basis of areal extent and depth of leaching and thought they were deposited during Tazewell, early Cary, and middle Cary time. Forsyth mapped glacial deposits in Licking County (Forsyth, 1966) and adjacent counties to the north (Forsyth, 1961) and south (Forsyth, 1962). In the report on the geology of Knox County (Root and others, 1961) north of Licking County, she noted varying degrees of leaching, clay-skin development, and silt-cap thickness among the Wisconsinan tills. She thus assigned local soil names to these tills. In the report on the geology of Fairfield County (Wolfe and others, 1962) to the south, Forsyth made her classic distinction between the Miami 60 and 6A soils, which represented Wisconsinan tills of slightly different ages. Her revisions of the glacial geology of these three counties appear on the 1967 revision of the glacial map of Ohio (Goldthwait and others, 1961).

Early attempts to correlate tills from Licking County to those in northeastern Ohio, specifically those of the Killbuck lobe, caused some confusion. Totten (1973) and White (1982) correlated their three Wisconsinan tills to those of Forsyth (table 2) and extended the correlation into the part of Richland County glaciated by the Scioto lobe. Fullerton (1986) mixed Killbuck-lobe and Scioto-lobe terminology (table 1). Totten and Szabo (1987) applied the Killbuck-lobe names to newly mapped counties within the northern part of the area glaciated by the Scioto lobe. They continued to use Killbuck-lobe terminology (Szabo, 1992; Szabo and Totten, 1995) because of uncertainties in the correlation of these units with those identified by Goldthwait and his students in the area glaciated by the southern part of the Scioto lobe.

Forsyth (1991) began to resolve this spatial dilemma by correlating the high-lime tills of the western part of the area covered by the Scioto lobe to tills in the central and eastern parts (table 2). As the tills were traced eastward, they became less calcareous because of the change in the underlying bedrock from carbonates to clastics. Anomalous areas of high-carbonate till on the Allegheny Plateau further complicated correlations (Szabo and Totten, 1992). Forsyth correlated the Centerburg and Mount Liberty tills to the Darby and Caesar Tills, respectively, which are older than the Hiram and Hayesville Tills.

Understanding of the Wisconsinan stratigraphy of the Scioto lobe continued to evolve as Richard Goldthwait, in cooperation with personnel of the Ohio Division of Geological Survey, prepared new Quaternary maps of Ohio. The maps for central Ohio (Goldthwait and Pavey, 1993; Goldthwait and Van Horn, 1993) suggest that the Scioto lobe advanced four times during the late Wisconsinan substage and support the belief of Forsyth (1991) that the Hiram and Hayesville Tills are younger than the Caesar and Darby Tills.

As the Navarre Till was traced out of the area glaciated by the Killbuck lobe into the area covered by the Scioto lobe, it began to display a wide range of carbonate contents. Some of this variation could be explained by the effects of the Allegheny escarpment on till composition, but other variations occurred within measured sections on the Allegheny Plateau, for example in Licking County. Szabo and Totten (1994) suspected that there might be multiple Navarre units in Licking County as suggested by Fullerton (1986). Szabo (1996 and summarized below) studied glacial stratigraphy in Hartford Township in the northwestern part of Licking County and concluded that there are two units of Navarre Till. Each unit consists of a basal meltout or lodgement diamicton having a fine-carbonate content typical of the Navarre Till, overlain by interstratified diamicton, silt, sand, and gravel having a larger fine-carbonate content and representing ablational processes. The bipartite nature of these two units permits them tentatively to be correlated with the Darby and Caesar Tills of the Goldthwait classification (table 2).

Illinoian tills

The terminology applied to Illinoian tills has followed a less tortuous path than that of the Wisconsinan tills. The Jelloway Till initially was considered to be middle Wisconsinan in age because it could be traced across the lobes in northeastern Ohio to the Titusville Till in northwestern Pennsylvania (White, 1982). Dreimanis and Goldthwait (1973) suspected that the Millbrook Till of the Killbuck lobe, which was correlated with the Jelloway Till (Totten, 1973), was possibly of Illinoian age because of the greater weather-

TABLE 1.—*Various interpretations of ages of tills of the eastern Scioto lobe*

Age	Forsyth (1961, 1966)	Totten (1973) White (1982)	Fullerton (1986)	Totten and Szabo (1987)	Szabo (1992)	Szabo and Totten (1995)
Late Wisconsinan	Centerburg Till Mount Liberty Till	Centerburg Till Mount Liberty Till Knox Lake Till	Hiram Till Mount Liberty Till Knox Lake Till	Hiram Till Hayesville Till Navarre Till	Hiram Till Hayesville Till Navarre Till	Hiram Till Hayesville Till Navarre Till
Middle Wisconsinan		Jelloway Till				
Early Wisconsinan	Knox Lake Till		Jelloway Till	Millbrook till U Millbrook till A		
Illinoian		Butler Till	Gahanna Till	Millbrook till BI Millbrook till BII Millbrook till BIII Millbrook till BIV	Millbrook till U Millbrook till A Millbrook till BI Millbrook till BII Millbrook till BIII Millbrook till BIV	unnamed till Northampton Till Millbrook Till Gahanna Till Chesterville Till
Pre-Illinoian			unnamed tills			Butler Till

TABLE 2.—Evolution of correlations of various Wisconsinan tills within the Scioto lobe

Totten (1973) and White (1982)		Forsyth (1991)			Goldthwait and Van Horn (1993) and Goldthwait and Pavey (1993)		
Killbuck lobe	*eastern Scioto lobe*	*western Scioto lobe*	*central Scioto lobe*	*eastern Scioto lobe*	*western Scioto lobe*	*central Scioto lobe*	*eastern Scioto lobe*
Hiram Till	Centerburg till[1]	Marysville Till			Lake till	Hiram Till	Hiram Till
Hayesville Till	Mount Liberty till[1]	Bellefontaine Till	Darby Till	Centerburg till	Marysville Till	Hayesville Till	Hayesville Till
Navarre Till	Knox Lake till[1]	Pickrelltown Till	Caesar Till	Mount Liberty till	Bellefontaine Till	Darby Till	Centerburg till
					Pickrelltown Till	Caesar Till	Mount Liberty till

[1]Forsyth (1961) originally mapped this unit by the type of soil developed on it, and the till inherited the soil name.

ing depth relative to known Wisconsinan tills. During the glacial mapping program of the Ohio Division of Geological Survey in the 1980's, Totten and Szabo (1987) recognized the multiple nature of the Millbrook Till. The term Jelloway was abandoned and the Millbrook Till was divided into informal subunits (table 1) on the basis of slight differences in color, texture, and reaction to hydrochloric acid.

At the Morrow County fairgrounds section in Mt. Gilead, a silt (loess?) overlying four of the Millbrook subunits had a thermoluminescence age of 125,400 ± 16,000 years B.P. (Alpha 3018), which suggests that these Millbrook subunits are Illinoian or older (Szabo and Totten, 1995). At its type section, the Millbrook Till is the subunit containing only a small amount of fine carbonate (Storck and Szabo, 1991). The name Millbrook Till is now restricted to this subunit. Szabo and Totten (1995) traced the most calcareous of the Millbrook subunits into Licking County and concluded that it correlated with the lower till at the Rocky Fork cut in Gahanna (table 1). Other subunits were correlated or formally defined; the two lowermost Millbrook subunits cannot be separated at this time and are known as the Chesterville Till. The assignment of the Millbrook subunits to the Illinoian glaciation caused a reevaluation of the older units (Szabo and Totten, 1995). Samples of Butler Till collected by Totten (1973) were reanalyzed; some correlated with identified Illinoian units, whereas others appeared to be older. The name Butler Till is reserved for these pre-Illinoian units (table 1).

ILLINOIAN GLACIATION IN LICKING COUNTY

Since the work of Leverett (1902) and continuing with Forsyth's (1966) glacial map of Licking County, the glaciated areas east of the North Fork-South Fork axis have been attributed to the Illinoian glaciation. Given the very patchy nature of tills in this hilly, bedrock-controlled topography, little work was done on the details of Illinoian stratigraphy. Clearly, ice advances into the county would have produced a highly irregular front given the strong topographic controls. Note that local relief was much greater, particularly in the western and central portions of the county, at that time. Numerous early studies examined the valley dependencies of the ice front; ice tongues extended as much as 6 miles (10 km) farther east within east-west-trending valleys relative to adjacent uplands in east-central Licking County (Carney, 1907a).

In 1992, Stan Totten and John Szabo collected over 160 till samples from outcrops and manmade exposures in Licking County. On the basis of the appearance and composition of these samples, they were able to prepare a stack map and to estimate the areal extent of various Illinoian and Wisconsinan till units (fig. 8). The easternmost samples of Illinoian Chesterville Till have been found along a north-south line about 3 miles (5 km) west of Newark. Ice that deposited the Gahanna Till appears to have advanced into western Licking County to a north-south line passing just east of Alexandria. Stream cuts near Alexandria show a complex stratigraphy, suggesting that the Gahanna ice readvanced and stagnated (Stop 2; fig. 2.2). Millbrook Till is the most areally extensive Illinoian deposit in the county and extends to the Illinoian limit in the southeastern part of the county. The Millbrook Till incorporated large amounts of local clastic rocks as ice moved over the largely bedrock terrain of the east-central part of the county. Most thick Millbrook Till is preserved along the sides of stream valleys; the Millbrook is thin to nonexistent on the ridgetops. In central and western Licking County, late Wisconsinan Navarre Till may overlie any of the Illinoian tills, suggesting either patchy deposition of Illinoian units or significant postdepositional erosion at times during the late Illinoian, Sangamonian, and Wisconsinan.

REGIONAL LATE WISCONSINAN GLACIAL CHRONOLOGY

The record of late Wisconsinan ice in central Ohio is quite detailed but open to considerable interpretation, particularly with regard to the dynamics of end-moraine formation and the mobility of the ice front (for example, Paris, 1985; Quinn and Goldthwait, 1985; Lowell and Stuckenrath, 1990). The lack of distinct boundaries indicating time breaks within layered deposits coupled with questions concerning the variability and hence stratigraphic reliability of many radiocarbon dates prevents a clear resolution of the sequence of depositional events (Lowell and Stuckenrath, 1990).

Late Wisconsinan ice advanced into Ohio about 24,600 years B.P. (White, 1968) and reached a near-terminal position about 21,000 years B.P. in Highland County (Rosengreen, 1974). Similar dates have been recorded elsewhere along the Scioto-lobe front, including one date of 21,400 years B.P. on wood recovered from till by Goldthwait in the South Fork valley south of Newark. The preponderance of spruce in the buried logs of Illinois, Indiana, and Ohio, coupled with palynological and faunal evidence, indicates that the ice advanced into an open spruce woodland similar to the modern boreal forest-tundra ecotone (Dreimanis and Goldthwait, 1973). The range of radiocarbon dates near the margin of the Scioto lobe and the overlapping pattern of moraine crests suggest that the outer limit of glacial ice oscillated for several thousand years.

In a regional synthesis of midcontinent ice-margin activity, Mickelson and others (1983) proposed synchronous advances of adjacent ice lobes in the southern Great Lakes region at approximately 21,000, 20,000, 19,000, 18,100, 17,200, and 16,700 or 16,100 years ago prior to the Erie Interstade, when ice temporarily retreated out of Ohio. Subsequent advances at about 15,500 and 14,800 years ago did not extend into Licking County or the Licking River watershed. Other researchers (Quinn and Goldthwait, 1979; Bleuer, 1980; Clayton and others, 1985) have proposed unstable ice margins characterized by surging advances and relatively rapid meltbacks in which adjacent glacial lobes and sublobes were potentially out of phase. Surging margins are favored by low topographic gradients as well as impermeable substrates such as clay-rich tills and lacustrine sediments, which allow pore-water pressure to support much of the weight of the overlying ice (Clayton and others, 1985). In contrast, Lowell and Stuckenrath (1990) propose a simple overall chronology for the Miami lobe: a single ice advance began about 22,000 years ago and reached its maximum extent at 19,700 years ago, followed by an abrupt recession about 15,000 years ago. They suggest a relatively stable southern ice margin and downplay the role of rapid deglaciations and readvances.

LATE WISCONSINAN GLACIATION IN EASTERN FRANKLIN AND LICKING COUNTIES

On the basis of regional information, glacial ice was present in Licking County through a period of at most 6,000

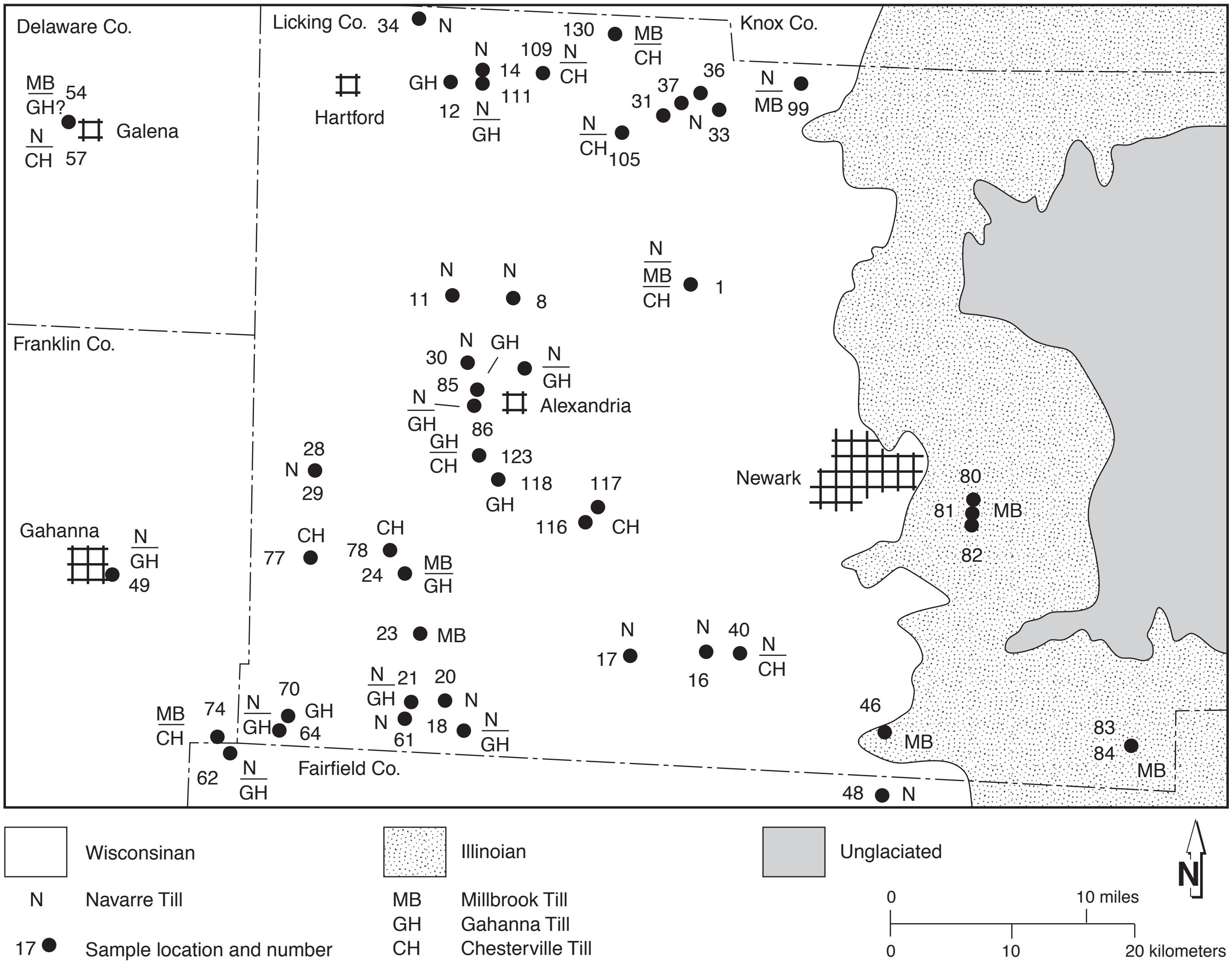

FIGURE 8.—Stack map based on diamictons exposed in outcrops in Licking County and adjacent areas. Wisconsinan and Illinoian boundaries drawn from Forsyth (1966).

years (22,500 to 16,500 years ago) over the past 120,000 years. Regional associations suggest a maximum ice extent in Licking County between 21,000 and 19,000 years ago. Hilly topography in portions of the north and central areas of the county would have retarded ice advances, whereas east-west valleys such as South Fork (Deep Stage Newark River valley), characterized by low relief and fine-textured fill, would promote saturated bed conditions and rapid ice advances.

Forsyth (1983), on the basis of topographic expression alone, distinguished a terminal moraine and two recessional end moraines along the edge of the bedrock hills of the Allegheny Plateau in Dawes Arboretum in eastern Licking Township. Several additional lobelike patterns of glacial deposits lie within the broad valley of South Fork to the west (see Forsyth, 1966). The degree to which these topographic features actually reflect a succession of late Wisconsinan ice advances is not known. Many end moraines formerly mapped as late Wisconsinan in Ohio are actually palimpsest moraines composed of older deposits capped by a thin mantle of Wisconsinan till (White, 1968; Mickelson and others, 1983; Paris, 1985). For example, the Johnstown Moraine, as mapped by Forsyth (1966), extends generally north-south through the western part of Licking County. The surficial Centerburg Till (Darby Till, table 2), which extends to and in places slightly east of the Johnstown Moraine, is thought to represent the last major advance of Wisconsinan ice into Licking County about 17,300 years ago. The Johnstown Moraine, not conforming to these most recent deposits, could represent an earlier ice-margin location, perhaps Illinoian or Wisconsinan or both.

According to glacial maps of Goldthwait and Pavey (1993) and Goldthwait and Van Horn (1993), late Wisconsinan ice advanced into Licking County at least twice. The limit of the first advance that deposited the Navarre (Mount Liberty, Caesar) Till is approximately the longitude of Newark. This advance generated significant outwash deposits at Newark and formed an end moraine south of the city (fig. 1). Ice retreated, depositing ground moraine and nonlinear hummocky moraine (Goldthwait and Pavey, 1993). Part of a recessional moraine is present in the west-central part of the county (fig. 1). The other part of this moraine was buried by ice of the second advance that deposited another Navarre (Centerburg, Darby) Till in an end moraine. Ground moraine and nonlinear hummocky moraine were formed as the ice wasted. A related recessional moraine is mapped in extreme northwestern Licking County. The double ridge may indicate the oscillating of the ice front. Ice melted back into Canada during the Erie Interstade (Dreimanis and Goldthwait, 1973) and readvanced to north of Columbus to deposit the Hayesville Till, which extends to the Powell Moraine (fig. 1). Following a brief recession, ice readvanced to deposit the Hiram Till to the Broadway Moraine north of Delaware. The diamictons of the advances prior to the Erie Interstade are loamy, whereas those after the interstade are more clay rich. The clay originated in proglacial lakes in the Erie Basin and was also derived from shales in the eastern end of the Erie Basin. Ice receded northward into the Erie Basin by about 14,000 years ago.

Correlations of data from 21 borings in Hartford Township in northwestern Licking County examined by Szabo suggest the presence of two late Wisconsinan tills and three Illinoian tills. The gently rolling ground moraine of the township is interrupted in its central part by two parallel rises of a north-south-trending recessional moraine having a local relief of 5-10 meters (fig. 1). The borings were made for an environmental study of a large poultry farm in the area.

A northwest-southeast cross section (A-A' on fig. 1) illustrates the Pleistocene stratigraphy of the area (fig. 9). The southeastern end of the cross section overlies a buried valley containing at least 150 meters of unconsolidated material, whereas shale forms the subcrop 12 meters beneath the surface at the northwestern end. Very firm, calcareous, olive-gray Chesterville Till (Illinoian) is the oldest glacial deposit penetrated by the borings (fig. 9). The adjacent sand and gravel unit in boring 13 has a large carbonate content, suggesting that it relates more closely to the overlying Gahanna Till than the Chesterville Till (fig. 9; table 3). The firm, calcareous, gray Gahanna Till, which directly overlies Chesterville Till, sand and gravel, or bedrock in this area, has the largest fine-carbonate content among the Illinoian tills. The Gahanna Till is overlain by a 2- to 3-meter layer of firm, weakly calcareous, calcite-deficient gray Millbrook Till (fig. 9).

Very little evidence of Sangamonian weathering is found at the contacts between the Illinoian and late Wisconsinan tills. Samples of Millbrook Till in many boreholes show weathering of chlorite on x-ray diffractograms, but only a few samples show any alteration of illite (figs. 10, 11). The weathering in some samples may be related to ground-water flow along contacts. In addition, the fine-carbonate contents of Illinoian samples near the boundary do not decrease.

Late Wisconsinan Navarre Till consists of two diamicton units containing lenses of silt, sand, and very calcareous gravel. Sand and gravel separates these units in many borings (figs. 9, 11). Depth relationships suggest that the friable to firm, calcareous, yellowish-brown to gray Navarre Till forms the constructional topography of the recessional and ground moraine. The silt and clay contents and fine-carbonate content of the Navarre Till are more variable than those of other units (table 3). Analysis of data showed that samples are clustered into a very calcareous group averaging 19 percent fine carbonate and a modestly calcareous group averaging nearly 7 percent (table 4). More calcareous samples seemed to overlie less calcareous samples in each of the two Wisconsinan units. The more calcareous samples are interpreted by Szabo to represent a supraglacial facies deposited by meltout near the glacial margin, whereas the less calcareous samples may represent deposition in the subglacial environment. The carbonate-rich rocks west of the Berea escarpment were probably a significant source area for the supraglacial deposits. Thus, the two couplets of subglacial and supraglacial glacigenic sediments represent two late Wisconsinan advances of ice into this part of Licking County.

POSTGLACIAL ENVIRONMENTAL CHANGE IN LICKING COUNTY

Pollen records from lacustrine organic sediments and peat indicate that spruce woodlands dominated the glaciated portion of Ohio in the early postglacial phase (Davis, 1983; Shane, 1987). The spruce woodlands gave way to mixed woodlands as fir, deciduous species including oak, ash, and ironwood, and nonarboreal species increased after 13,500 years ago. A modest spruce resurgence suggesting cooler summer temperatures between 11,000 and 10,500 years ago was followed by a brief increase in pine, suggesting drier conditions and then a shift to largely deciduous forests by 10,000 years ago (Shane, 1987). Pollen and paleolimnology studies of peat cores from wetlands in north-central and south-central Licking County generally confirm this regional picture (C. J. Woltemade, 1987, unpublished pollen diagram for Smoots Lake core, Ohio Wesleyan University; Lepper and others, 1991).

No modern analogs exist for many of the plant associations present during the postglacial period (15,000 to 10,000 years ago), so temperature and moisture estimates derived solely from the pollen record are problematic. Recent postglacial temperature estimates based on a synthesis of pollen and lake-level data indicate a dramatic 11° to 12°C warming of both mean July and mean January temperatures in central Ohio between 15,000 and 9,000 years ago (Webb and others, 1993). Comparisons with computer climate models show a large uncertainty in January temperature estimates.

ACKNOWLEDGMENTS

We express our sincere appreciation to all who have given us permission to visit their property. In order of the field-trip stops, thanks to Scott Richardson and the Board of Directors of the Rocky Fork Hunt and Country Club for access to the Rocky Fork exposure, Don Handel and Dean Lee for access to Dry Creek, the Hanover Township trustees for access to the Seven Hills Road site, Roger Cartnal and Scot Postle for repeated visits to lower Rocky Fork, and the Reverend Lloyd Kirk for access to the Christian Life Center Camp on lower Brushy Fork. Many current and former Denison students have worked on field projects that contributed valuable information for this field guide, and some brave souls volunteered their labor to prepare exposures. Darrin Gardiner, Matt Pachell, and Shanan Peters deserve special recognition. You could not be perusing this text without the efforts of Merrianne Hackathorn and Lisa Van Doren of the Ohio Division of Geological Survey. We thank them for their careful editing and design that transformed our manuscript into this field guide.

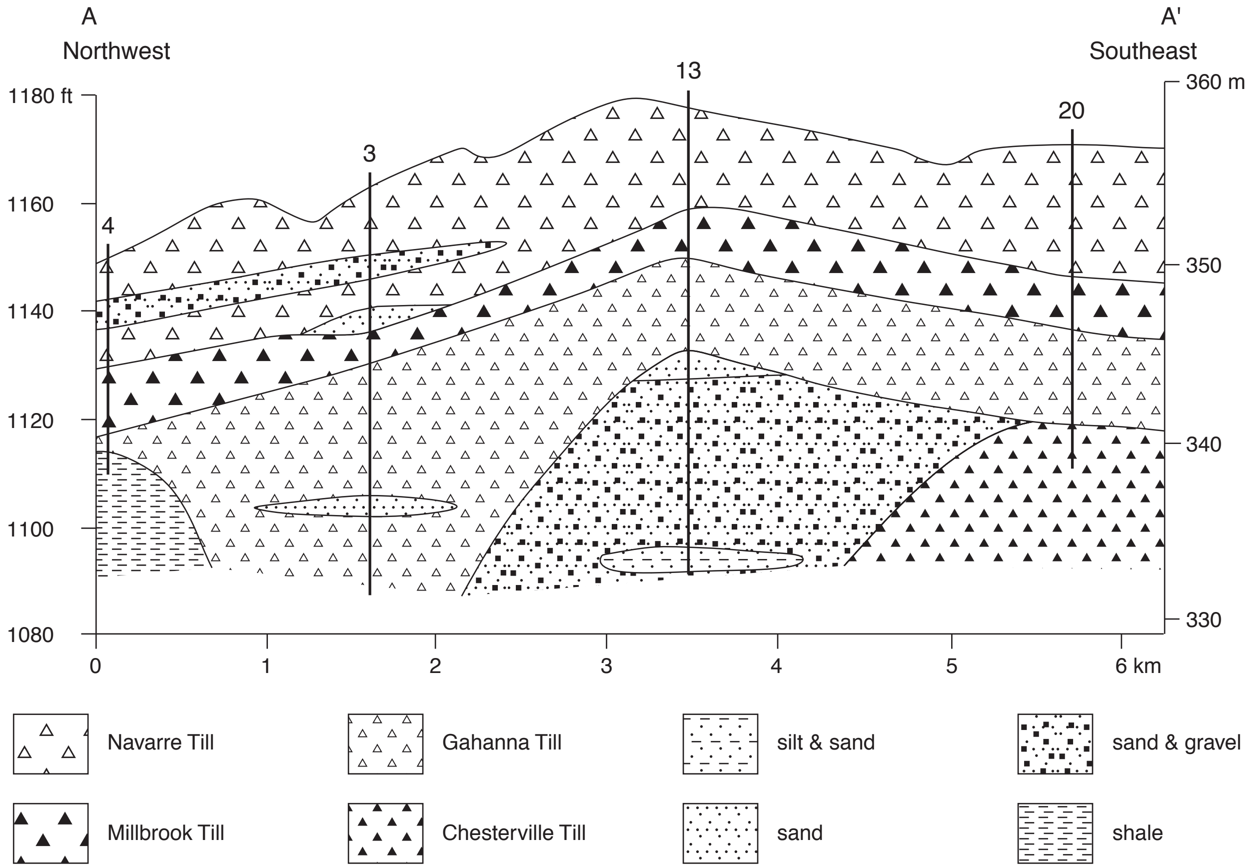

FIGURE 9.—Stratigraphic cross section A-A' near Hartford in northwestern Licking County. See figure 1 for location. Numbers indicate borings across the section. Vertical exaggeration 32:1.

TABLE 3.—*Summary of laboratory analyses*[1] *of tills from a reconnaissance survey of Licking County by S. M. Totten in 1992 and subsurface data from environmental borings in Hartford Township in northwestern Licking County*

Unit	sand	silt	clay	cal	dol	total carb	DI
Navarre Till[2]							
x	30	44	26	1.8	9.3	11.1	1.7
SD	6	10	10	1.1	5.1	7.4	0.8
n	123	123	123	123	123	123	90
Millbrook Till							
x	29	47	24	0.6	5.9	6.5	1.2
SD	5	7	7	0.5	1.8	1.9	0.2
n	54	54	54	54	54	54	49
Gahanna Till							
x	34	44	22	3.4	11.6	15.0	1.2
SD	7	8	9	1.5	4.4	5.2	0.3
n	105	105	105	105	105	105	102
Chesterville Till							
x	32	48	20	1.8	7.8	9.6	1.1
SD	5	7	7	1	2.1	2.5	0.3
n	50	50	50	50	50	50	49

[1] *x* = mean, SD = standard deviation, *n* = number of samples, cal = calcite, dol = dolomite, carb = carbonate, DI = diffraction intensity ratio.

[2] Navarre Till was not differentiated into subunits corresponding to the Darby and Caesar Tills.

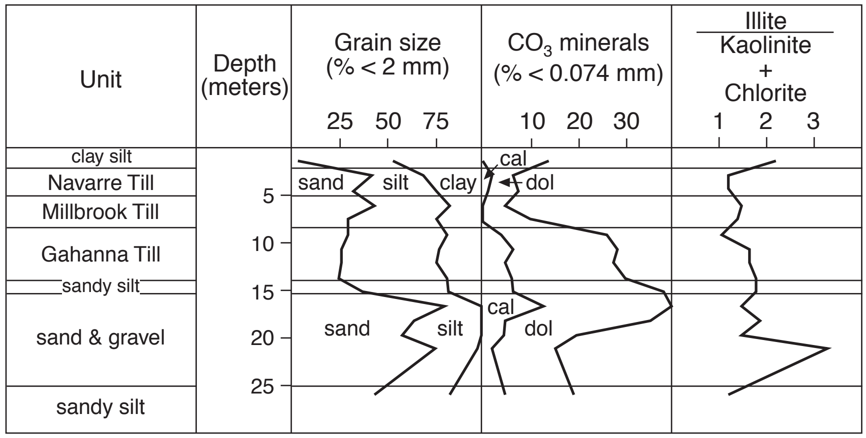

FIGURE 10.—Summary of laboratory analyses of units in boring 13 along cross section A-A'. See figure 9 for location.

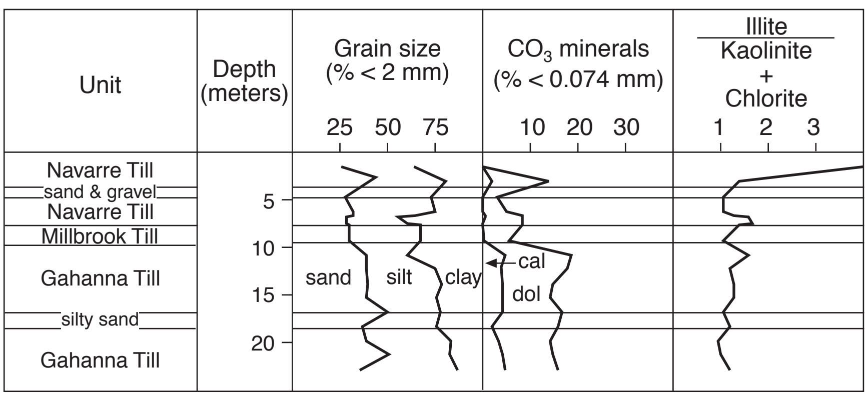

FIGURE 11.—Summary of laboratory analyses of units in boring 3 along cross section A-A'. See figure 9 for location.

TABLE 4.—*Comparison of laboratory data*[1] *from different facies of the Navarre Till*

Facies	sand	silt	clay	cal	dol	total carb	DI
supraglacial							
x	30	45	25	3.9	15.1	19.0	2.1
SD	7	7	8	2.4	3.9	5.7	0.9
n	28	28	28	28	28	28	27
subglacial							
x	31	43	26	0.8	6.1	6.9	1.6
SD	6	8	8	0.6	2.1	2.3	0.3
n	51	51	51	51	51	51	51

[1]*x* = mean, SD = standard deviation, *n* = number of samples, cal = calcite, dol = dolomite, carb = carbonate, DI = diffraction intensity ratio.

PART 2: ROAD LOG

by Tod Frolking

LEG 1, OSU OHIO UNION TO ROCKY FORK EXPOSURE AT GAHANNA (STOP 1) 11.5 MILES (18.5 KM)

Please excuse the scant Quaternary commentary for this largely urban/suburban portion of the trip. Our main goal is to get out of Columbus as quickly and smoothly as possible. Travel instructions are in *italics*. Mileages within the instructions are from one point to another and are not cumulative.

From the Ohio Union on the Ohio State University (OSU) campus, head east on W. 12th Avenue, cross High Street, and continue east on E. 12th Avenue. Turn right (south) onto Summit Street. Continue south on Summit Street (which becomes Third Street close to downtown Columbus) to the I-670 east entrance ramp. Proceed east on I-670, then bear north paralleling Alum Creek, then northeast, crossing Alum Creek and passing northwest of Port Columbus International Airport. Follow I-670 to U.S. Rte. 62 over I-270 (Jack Nicklaus Highway) and continue east on U.S. 62 into Gahanna. Cross Big Walnut Creek onto Ohio Rte. 317 (Granville Street) and continue east for 0.7 mile (1 km) to the first major intersection, Hamilton Road. Turn left (north) onto Hamilton Road. Cross Rocky Fork at 0.25 mile (0.4 km) then bear right (northeast) at 0.35 mile (0.6 km) onto Clark State Road (Franklin County Road 95). In about 0.7 mile (1 km) turn right (south) into Rocky Fork Hunt and Country Club. Descend into abandoned bedrock meander loop of Rocky Fork, ascend onto small bedrock remnant, past club buildings, and down gravel road to Rocky Fork floodplain. Park near shelter building. Cross Rocky Fork at opportune location, noting exposures of pink Bedford Shale (Upper Devonian), and walk south to Pleistocene exposure on south side of abandoned channel.

LEG 2, ROCKY FORK TO MOUNTS FARM EXPOSURES ON LOBDELL CREEK (STOP 2) 18.6 MILES (30 KM)

Leave Rocky Fork Hunt and Country Club and turn right (northeast) onto Clark State Road. This scenic route takes us gradually up the bedrock section and toward the higher elevations of the glaciated margin of the Allegheny Plateau. After crossing Rocky Fork, we climb onto the weakly defined Berea escarpment and gain 30 meters (100 feet) by the intersection of New Albany-Reynoldsburg Road.

Turn left (north) onto New Albany-Reynoldsburg Road and then immediately right (east) onto Kitzmiller Road. This road trends generally north-northeast just to the west of Blacklick Creek, which is the easternmost drainage in the Scioto River basin. We pass over gently undulating terrain increasingly occupied by white fences enclosing developments of the New Albany Company and gain another 20 meters (65 feet) by the intersection of old Ohio Rte. 161.

Turn right (east) onto old Ohio Rte. 161, cross Blacklick Creek, and proceed to intersection with the New Albany bypass (new Ohio Rte. 161) near the Franklin-Licking County line. Turn right (east) onto Ohio Rte. 161 at an elevation of about 340 meters (1,120 feet). Traffic on 161 has increased manyfold over the past decade as housing developments in the western and central parts of Licking County increasingly serve as bedroom communities for Columbus. As most commuters drive alone in ever larger and heavier vehicles, we in central Ohio are doing our best to delay the onset of the next glacial cycle. As the climate warms with an enhanced greenhouse effect, we'll have fewer acres to plant in subtropical crops. Licking County lost about 40,000 acres (14 percent) of its farmland between 1970 and 1995, and developments in the western part of the county have accelerated since 1995.

Here we are on a fairly flat till plain along the divide between the upper reaches of the Raccoon Creek drainage to the north and the South Fork Licking River drainage to the south (U.S. Geological Survey Jersey 7.5-minute quadrangle). The pre-Wisconsinan past is well hidden here. About 1.6 miles (2.6 km) east of the county line, between Harrison and Mink Roads, we pass over the axis of a deep, south-trending buried valley containing over 125 meters of fill (Dove, 1960; see fig. 4 and discussion of the region's paleodrainage history in Part 1 of this guidebook). East of this buried valley, bedrock interfluves rise to over 335 meters (1,100 feet), and the depth of Pleistocene cover is more modest but still considerable as we gradually climb to an elevation of 373 meters (1,230 feet) about 1.5 miles (2.5 km) east of Mink Road.

East of the intersection with Ohio Rte. 310, the terrain grows notably more dissected and hummocky as we cross northeast-flowing tributaries to Raccoon Creek. Simpson Run has incised into bedrock at numerous points. We cross it at an elevation of 310 meters (1,020 feet) 1.9 miles (3 km) east of Ohio Rte. 310.

Turn north (left) onto Ohio Rte. 37. We descend through a kame field on the south flank of Raccoon Creek valley and pass by more kames protruding out of the modern floodplain. We cross Raccoon Creek at an elevation of 285 meters (935 feet) and then climb onto a high Wisconsinan outwash surface at 300 meters (990 feet) as we come into the center of Alexandria. Water-well logs around the village reveal a predominance of sand and gravel in the upper 15 meters. Many residents have relatively shallow wells (15 meters), and the area has a history of water contamination problems.

Turn right (north-northeast) at the stoplight onto Mounts Farm Road. We descend to the broad cut surface that extends around the north side of Alexandria, then ascend onto an undulating till plain. Here we are along the margin of the late Woodfordian (post-18,000 years B.P.) Centerburg Till as mapped by Goldthwait and Pavey (1993). Mounts Farm homestead, which burned down in the mid-1990's, was located on the right (west), just before our descent into the valley of Lobdell Creek. *Cross Lobdell Creek and park at gas-well access road. Walk east-northeast across the field and through the woods to the Lobdell Creek exposures.*

Three locations along this reach of Lobdell Creek reveal thick sequences of glacial diamicton and glaciofluvial deposits. The two adjacent sites at this stop (south and north) are ideal because of their accessibility and location on now state-owned land in what was to be the impoundment area for the Lobdell Creek dam (downstream, 600 meters southwest of here). This dam and reservoir were to be a major component of a flood-control plan of the South Fork Conservancy District. The plan was revealed to the general public in 1993 in a mailing of proposed charges to property owners. This conservancy plan, developed in response to the January 1959 floods which ravaged much of Ohio, had finally worked its way through the U.S. Congress and received partial funding. At about the same time, following the great floods in the Mississippi River basin during the summer of 1993, Congress was finally recognizing the value of less floodplain development and associated flood-control structures. The plan was generally unpopular given its cost to property owners. The facts that the Lobdell Creek reservoir would have minimal effect on the flood-endangered portions of the Licking River basin and would principally benefit developers and Franklin County boaters did little to generate public support.

Although the gas well here has not been very productive for CGAS Exploration, Inc. (formerly Clinton Oil Company), several wells in St. Albans Township have been. Drilling for natural gas has expanded westward in this part of Ohio as both seismic-modeling capabilities and understanding of subsurface stratigraphy have improved. Here drillers are seeking outliers of the Cambrian-Ordovician Rose Run sandstone and overlying "Beekmantown" dolomite at depths of about 1,200 meters. Current thinking is that the Cambrian-Ordovician terrain here was similar to the tower karst topography of parts of Puerto Rico or northern Guangxi Province in China. A middle Ordovician transgression (post-Knox unconformity) covered this landscape with fine-grained sediment that now caps these permeable sandstone/dolomite traps. The problem is to determine the spatial pattern of the steep-sided outliers, which undoubtedly has both lithologic and joint control. It's an interesting blend of geophysics, stratigraphy, and paleogeomorphology.

LEG 3, MOUNTS FARM TO WILDWOOD PARK/GRANVILLE WELL FIELD (STOP 3)
5.9 MILES (9.5 KM)

Head south on Mounts Farm Road, turn left (southeast) onto Ohio Rte. 37 and then left (east) at Y junction onto Raccoon Valley Road, which follows the north side of Raccoon Creek valley to Granville. At 0.9 mile (1.5 km) cross Lobdell Creek near its confluence with Raccoon Creek.

At 1.5 miles (2.5 km) note the broad valley floor and low elevation of the hills flanking the north side of the valley. This topography marks the confluence of a major tributary from the north with pre-Wisconsinan Raccoon Creek. Damming by ice/moraine in the lower reach of this valley led to ponding, drainage reversal, and the cutting of a steep bedrock narrows on Dry Creek about 4 miles (7 km) to the northeast. The area northeast of this hummocky valley fill now drains into the North Fork Licking River. We will intercept the Dry Creek valley just east of the narrows after our Granville rest stop.

Raccoon Valley Road then climbs onto valley-side ice-contact deposits consisting of kames and small kame terraces. Water-well logs show variable and laterally discontinuous sand/gravel and "clay" deposits, suggesting local ice-contact sediment deposition as opposed to any continuous valley-train type of deposit. Several large kames are present in the center of the valley.

Turn left (east) onto Newark-Granville Road. The Raccoon Creek floodplain is on the right (south) and a steep bedrock hill held up by the Byer Sandstone Member of the Logan Formation is on the left (north). *Turn right (south) into Wildwood Park for coffee break and contemplation. (In case of inclement weather, an alternative rest stop will be on the Denison University campus).*

LEG 4, WILDWOOD PARK TO LOWER DRY CREEK EXPOSURE (STOP 4)
7.5 MILES (12 KM)

Turn right (east) onto Newark-Granville Road (West Broadway). We ascend onto a small kame terrace surface. Recent sewer work on Thresher Street (on left) uncovered a large subrounded erratic (>1 meter in diameter), further evidence that much of the surficial material in this terrace was from local glacial meltout. We pass by Sugarloaf Park (a bedrock outlier) on the right (south) and ascend onto the Granville Terrace, which has an average elevation of 295 meters (970 feet).

This high surface, protected by bedrock outliers to the east and west, lies well above other terraces in the valley and has been problematic in attempts to correlate terrace surfaces within the valley (Jones, 1959). If it is an isolated, valley-side ice-contact deposit, its elevation need not correlate with other surfaces. Well logs on this surface and lower terraces to the east reveal variable stratigraphies of sand/gravel and "clay."

A test well drilled by Metcalf and Eddy on the south edge of the Granville Terrace brought up leached, oxidized yellowish-brown 10YR 5/4 loamy diamicton at a depth of about 9 meters and calcareous, gray 10YR 4.5/1 loamy diamicton below at a depth of 16 to 17 meters. Unfortunately, I examined only two short core sections, but the upper sample appears to be a well-drained paleosol (Sangamonian?), suggesting that both samples are Illinoian. To the east of Granville, a foundation excavation in a kamelike hill rising above the high Wisconsinan terrace revealed a thin (1 meter), calcareous diamicton (Wisconsinan) over leached, brown sand and gravel containing abundant clay films (Sangamonian paleosol). It may be that a significant portion of the valley-side terrace materials is in fact Illinoian.

Granville, home of Denison University, was founded in 1806 by settlers from Granby, Connecticut, and Granville, Massachusetts. The community continues to have a strong sense of historic preservation; over 100 houses and buildings are on the National Register of Historic Places. Most of Licking County was part of the U.S. Military Tract, whose lands were deeded to Revolutionary War veterans in lieu of monetary compensation. Reliable sources have said that the Old Granville Cemetery has more veterans of the Revolutionary War than any other cemetery west of the Appalachians. Like many attractive, peaceful, and therefore desirable towns today, Granville is struggling to maintain a small-town ambience in the face of development pressures.

Turn left (north) onto North Pearl Street (Ohio Rte. 661), curve around the bedrock hill on the left, then turn right (northeast) onto Cedar Street, which leads to Welsh Hills Road. We cross Clear Run just below its confluence with Clay Run, which drains much of the Denison University Biological Reserve just north of here. Like its larger namesake, Claylick Creek, which drains into the Licking River a bit west of Black Hand Gorge (Stop 7), Clay Run drains an area of extensive lacustrine deposits and, therefore, silt and clay are exposed in cutbanks. In the center of the bioreserve, these calcareous deposits are overlain by a thin (typically about 1 meter) diamicton that commonly contains gravelly zones. A similar stratigraphy was found in Munson Hollow, a small south-draining valley about 1.5 miles (2.5 km) to the east. These sites suggest local ponding as a tongue of late Wisconsinan ice extended down the Raccoon Creek valley, dammed lateral tributaries, and eventually expanded over much or all of the area.

Follow Welsh Hills Road generally northeast through the scenic Welsh Hills for about 5 miles (8 km). We soon leave the Raccoon Creek drainage and enter the North Fork Licking River drainage; we descend into and climb out of Sharon Valley and Log Pond valley before entering the Dry Creek valley 0.7 mile (1 km) downstream from its narrows. As we cross Dry Creek, note the channel form, dimensions, and character of bedload. In the reach visible from the bridge, the channel gradient is 0.0039, which is typical for streams of this size in the area.

Turn right (east) onto Dry Creek Road and continue down valley to Greenland Drive and turn right (south). We are now on the broad, high-Wisconsinan Vanatta Terrace at about 277 meters (908 feet), named after the town of Vanatta just to the northeast (Jones, 1959). We are at the confluence of the outwash surfaces developed in the Dry Creek and North Fork valleys. Here the gentle eastward slope of the terrace surface suggests a Dry Creek source (check out the gravel imbrication at the Dry Creek exposure). Driving south, we drop down off the Vanatta Terrace onto the lower Utica Terrace, which Jones (1959) attributed to a late-glacial readvance into the North Fork watershed in the vicinity of Utica in north-central Licking County. *Jog right (west) on Berkley Drive then left (south) onto Greenland Circle West and park in the cul-de-sac. Walk south off the Utica Terrace onto a Holocene terrace and down into the Dry Creek channel.*

LEG 5, DRY CREEK TO OSU NEWARK CAMPUS (LUNCH STOP) 5.3 MILES (8.5 KM)

Head north on Greenland Drive, turn right (east) onto Dry Creek Road, bear right (southeast) onto Marion Road (Ohio Rte. 657), and then turn right (south) onto Mount Vernon Road (Ohio Rte. 13). Cross Dry Creek then take the first right (west) onto North Vernon Avenue and once again cross the broad Vanatta Terrace. Bear left (south) onto Riggs Road, turn right (west) onto Price Road, and then left (south) onto King Road, crossing the mouth of Log Pond valley.

Good views of the North Fork valley can be had as we climb the noses of some bedrock spurs on the west side of the valley. Looking across the valley to the east-northeast, Illinoian deposits have partially filled a former west-flowing tributary to the Deep Stage Utica River (Stout and others, 1943) and formed a broad sag in the elevation of the bluffs. We will climb onto that Illinoian surface and follow the reversed drainage eastward after lunch. *Jog right (east) onto Sharon Valley Road, then turn left (south) onto Country Club Drive to our lunch stop at the Newark campus of the Ohio State University.*

LEG 6, OSU NEWARK CAMPUS TO SEVEN HILLS ROAD EXPOSURE (STOP 5) 17.1 MILES (27.5 KM)

Retrace route north on Country Club Road, east on Sharon Valley Road, and north on King Road, then turn right (east) onto Goosepond Road. Turn right (south) onto North 21st Street and left (east) onto Deo Drive. Jog onto Mount Vernon Road (Ohio Rte. 13) and continue east on Waterworks Road, descending several cut terraces down to the Newark Water Works treatment plant, and cross the North Fork Licking River at an elevation of about 250 meters (820 feet). Turn left (north) onto Horns Hill Road and pass around Horns Hill. The westward-sloping surface here marks the easternmost extent of late Wisconsinan ice, according to Forsyth (1966). The Quaternary geology map of the Marion quadrangle (Goldthwait and Pavey, 1993) has the Woodfordian glacial limit at the bluffs on the west side of the North Fork valley north of Newark but extending across the South Fork valley and into tributary valleys on its east side south of Newark (fig. 1).

Turn right (east) onto Stewart Road. The hill immediately to the left is mapped as an Illinoian kame (Forsyth, 1966) protruding though the Wisconsinan fill. We now ascend a dissected Illinoian moraine surface that grades eastward into an Illinoian outwash surface at the top of the climb at about 310 meters (1,020 feet). *Turn left (north) onto Martinsburg Road (Licking County Hwy. 204).*

We are now on the proximal edge of a large Illinoian outwash plain. Meltwater drainage was down Lost Run (to our east) into Rocky Fork, which enters the Licking River valley at Hanover. Lying close to the Wisconsinan margin and the North Fork outwash deposits, this Illinoian surface is mantled by up to 1.75 meters of Wisconsinan loess (Khangarot, 1969). Two cores by Frolking on the broad Illinoian surface 1 mile (1.6 km) to the east (SW$^1/_4$NE$^1/_4$ sec. 25, T 3 N, R 11 W) revealed 2.6 and 2.85 meters of loess over a banded mixed zone over a pebbly, yellowish-red Sangamon B horizon. Who says there's not much loess in Ohio? In one core the loess became calcareous at 1.98 meters; the other core was leached throughout. It is not clear to what extent these very thick silty deposits may reflect a colluvial infilling of swales (that is, reworked loess to some extent). A thinner exposure of loess over a mixed zone over Illinoian outwash will be examined at Stop 5 about 7.5 miles (12 km) to the east.

Turn right (east) at Licking Springs Road then left (north) and then immediately right (east) onto Swisher Road. We now descend into the modern drainage of Wilkins Run, which has incised into the high Illinoian surface clearly visible to the south. At Stop 6 we will examine leached fluvial gravels of probable Wisconsinan age in the lower reaches of Rocky Fork. Headward entrenchment into Illinoian terrace deposits such as these is a likely source for the gravel. The small gravel pit off to the right (south) has been abandoned because of the prominent 0.5+-meter-thick calcrete layer (calcite-indurated gravels) lying perhaps 6 meters below the Illinoian terrace surface. The modern drainageway on the flank of the pit truncates the calcrete layer, indicating that the carbonates are largely a relict feature (Sangamonian?) predating the latest phase of headward valley incision.

Turn right (south) onto Fallsburg Road (Ohio Rte. 79), then take the second left (east) onto Eddyburg Road. Although we are still inside the mapped Illinoian ice limit, the impact of glaciation on the bedrock upland terrain in this area has been minimal.

Turn right (southeast) onto Swans Road and descend into scenic London Hollow valley, which drains due south into the Licking River valley. Turn right (south), continuing on Swans Road at an elevation of 272 meters (893 feet). As we move down valley, the broad bottom suggests some degree of aggradation (colluvial or lacustrine). Farther east, lacustrine deposits from a probable late Wisconsinan glacial lake have been found at elevations of 255 meters (840 feet). This is the approximate elevation of the broad London Hollow bottom.

Turn left (east) onto Bolen Road. We are now traversing dissected Illinoian deposits on the north flank of the Licking River valley. Forsyth (1966) mapped this area as Illinoian kame terrace. A number of well logs, however, suggest a preponderance of fine sediments, perhaps due to damming of local south-flowing tributaries or more widespread ponding of the westward-flowing pre-Illinoian drainage by a Licking Valley ice lobe. Few remnants of flat Illinoian terrace surfaces occur in this stretch of the valley and the genesis of this terrain remains unclear.

Bear left (northeast) onto Licking Valley Road. Climb to a fairly flat surface at about 284 meters (930 feet). This surface may grade to the broad, flat Illinoian outwash surface at about 277 meters (910 feet) that can be seen to the east of Rocky Fork valley and Hanover. Descend through the dissected flank of the high Illinoian surface toward Rocky Fork. A small gravel pit off to the north reveals a beautiful northward-prograding deltaic sequence linked to nearby Illinoian ice. What appears to be late Wisconsinan lacustrine silt and fine sand (no analyses to date) occur in low areas (<255 meters/840 feet) immediately to the north and continue under gravels mantling the high Wisconsinan terraces.

Cross Rocky Fork in downtown Hanover and continue northeast on Licking Valley Road onto the flat Illinoian surface. The bedrock hills rising 30 to 60 meters above this surface to the north and south mark the valley walls of the Deep Stage Newark River valley. Pleistocene fill in the valley center is at least 105 meters (Pavey, 1995). Illinoian glacial ice and valley-fill deposits in this vicinity blocked the main valley of the Deep Stage Newark River, creating a large proglacial lake which eventually overtopped and incised through a divide near McConnelsville in Muskingum County, forming the modern Muskingum River (see fig. 4). *Make a hard right (south) turn onto Seven Hills Road and proceed about 0.5 mile (0.8 km) to Stop 5.*

LEG 7, SEVEN HILLS ROAD TO CARTNAL/POSTLE EXPOSURE ON ROCKY FORK (STOP 6) 2.4 MILES (3.9 KM)

Continue south on Seven Hills Road. Pass the Bowerston Shale Company brickyard on the right (east). Cross railroad tracks, continue straight at junction with Marne Road, and cross over Ohio Rte. 16. In the now-inactive Bowerston Shale quarry directly ahead, shale and siltstone were quarried for brick production from the Allensville and Vinton Members of the Logan Formation.

Turn right (west) onto Rock Haven Road (Twp. Road 275). Here the contact between the thinly bedded Byer Sandstone and Berne Conglomerate Members of the Logan Formation and the massive Black Hand Sandstone Member of the Cuyahoga Formation cannot be missed. Note the numerous Black Hand exposures as we descend through a bedrock narrows that now contains the lower reach of Rocky Fork. *Where Rock Haven Road turns east and goes uphill toward Toboso, stay in the valley on Twp. Road 275A and continue southward to the Cartnal/Postle property (Stop 6), which sits on a small terrace remnant. Park beyond the house.*

LEG 8, CARTNAL/POSTLE EXPOSURE TO LOWER BRUSHY FORK AND BLACK HAND GORGE (STOP 7) 5.5 MILES (8.8 KM)

Retrace route north on Twp. Road 275A and Rock Haven Road, cross Ohio Rte. 16, and turn left (west) onto Marne Road. Descend into Rocky Fork valley and the town of Hanover. Turn left (southwest), continuing on Marne Road. We pass along the south flank of a bedrock hill isolated by the modern drainages of Rocky Fork to the east, the Licking River to the south, and the Deep Stage Newark River to the north. Road cuts afford excellent exposures of the Black Hand Sandstone Member and overlying Berne Conglomerate and Byer Sandstone Members. This is perhaps the best view of the modern Licking River floodplain. Our final stop at the mouth of Brushy Fork valley can be seen to the south, and the entrance to Black Hand Gorge is off to the southeast.

Turn left (south) onto Brownsville Road (Licking County Hwy. 668) and cross Ohio Rte. 16 and then the Licking River. Bear left (east) onto Brushy Fork Road and immediately cross Claylick Creek. This stream is aptly named, as lacustrine sediments and fine-textured diamictons (Illinoian) are exposed along much of both Claylick Creek and its eastern tributary, Little Claylick Creek. Claylick Creek captured a significant portion of west-draining Swamp Run, presumably when Wisconsinan ice filled the South Fork Licking River valley and blocked Swamp Run, resulting in the breaching of the Claylick divide 3.7 miles (6 km) west-southwest of here. Just upstream from here, Claylick Creek is now locked into a bedrock channel as the stream incised following the late Wisconsinan aggradational phase. Farther upstream, the channel reveals Illinoian diamictons extending as much as 1 meter up both banks, indicating that the channel (1) has not moved, (2) was artificially relocated, or (3) is actively incising (similar to the condition of Lobdell Creek and numerous other streams in the area).

As we climb over the low divide at 287 meters (940 feet) into the Brushy Fork basin, we pass into true “Driftless Area.” The topography and stratigraphy of the lower Brushy Fork valley is much the same as that of the Rocky Fork and Claylick Creek valleys. The modern floodplain is inset into terraces composed of braided channel deposits over lacustrine sediments. Here the gravels are local, consisting mostly of flint associated with limestones of the lower and middle Pennsylvanian Pottsville and Allegheny Groups. The few samples of lacustrine sediments analyzed from this basin have twice the carbonate content of those from glaciated basins such as Claylick Creek and Rocky Fork. Because the carbonates in Brushy Fork could only come from loess or local limestones, the high carbonate content argues for a strong period of landscape destabilization at the time of Glacial Lake Licking to allow for the significant erosion of local carbonate bedrock or the calcareous residual soil mantle (Glacial Lake Licking is discussed under Stop 6 in Part 3).

Turn left (north) at base of hill and drive onto property of Christian Life Center Camp. Park at north end of road. Walk north out of the Brushy Fork valley into the Licking River valley and onto floodplain. Walk east on bike path into Black Hand Gorge.

LEG 9, BLACK HAND GORGE BACK TO OHIO UNION ABOUT 50 MILES (80 KM)

Retrace route northwest on Brushy Fork Road and north on Brownsville Road (Licking County Hwy. 668). Turn left (west) onto Ohio Rte. 16. This faster but less scenic route back to Columbus first heads up the Licking River valley to Newark.

The one “scenic” addition to this portion of the route is east of Newark: the headquarters of the Longaberger Co., manufacturer of—you guessed it—baskets. This building and property lie on a mixed bag of diamicton and lacustrine and outwash deposits. Although the diamicton could be Illinoian, its relatively high elevation in the center of the valley and its close association with Wisconsinan terrace gravels suggests that it is most likely late Wisconsinan. Thus it appears that a tongue of Wisconsinan ice extended eastward at least 2.5 miles (4 km) up the Licking River valley beyond its general margin along the bedrock hills forming the east flanks of the North and South Fork valleys. It was probably this ice tongue that created Glacial Lake Licking and resulted in the final cutting of Black Hand Gorge in early Woodfordian time.

Excavations and test borings at the Longaberger site revealed a thin cover of outwash sand and gravel mantling the series of stepped terraces extending down from the high-Wisconsinan terrace just to the north of the property (BBC&M Engineering, 1995). The bulk of the valley fill material here, and up and down the Licking River valley, is fine diamicton and lacustrine sediment. The current interpretation is that these terraces are primarily degradational, tied to the cutting of Black Hand Gorge to the east and perhaps the recession of the glacial margin to the west. There is no evidence of significant cutting and filling after the formation of the high terrace.

As we enter Newark, the Owens Corning Fiberglas plant (a major employer) can be seen to the right (north) and then the Licking County courthouse to the left (south). On the west side of Newark at the Dugway, we pass good exposures of the Raccoon Shale Member of the Cuyahoga Formation, the time-stratigraphic equivalent of the coarser Black Hand Sandstone Member, as well as the overlying Berne and Byer Members of the Logan Formation. The Raccoon Shale Member, here composed principally of thinly bedded fine sandstone and siltstone, continues to fine westward (Bork and Malcuit, 1979).

As we continue west on the main road, passing by Granville and Alexandria and many beautiful kames on the south flank of Raccoon Creek valley, the state route number changes from 16 to 37 to 161, a challenge to all who give directions. We continue west on Ohio Rte. 161 to I-270 north and west, to I-71 south, to 17th Avenue, west to High Street, and south to the Ohio Union. Feel free to make geologic interpretations at will.

PART 3: DESCRIPTIONS OF STOPS

STOP 1, ROCKY FORK EXPOSURE AT ROCKY FORK HUNT AND COUNTRY CLUB IN GAHANNA

by John Szabo

The units at this site were deposited in a bedrock paleovalley incised into the Berea Sandstone and underlying Bedford Shale. Glacial deposits on the surrounding higher bedrock terrain are thinner. Most thick exposures of glacial deposits in central Ohio are found along stream banks, and many of these are located in deep bedrock valleys. The correlation of deeper units among these exposures is inherently problematic because many tend not to be laterally continuous. In addition to the glacial history, the units present at Rocky Fork depend on the pre-Illinoian and pre-Wisconsinan erosional history of the landscape and the local relief at the time of glaciation.

The original section (Goldthwait and others, 1965) is located on a presently covered, east-facing bank of Rocky Fork, 70 meters north of Havens Corners Road. The section used in this field guide is located on a north-facing cutbank 40 meters from the original section.

Historical overview

The stream cut along Rocky Fork has been studied for nearly a century. Stauffer and others (1911), while mapping the Columbus quadrangle, thought that there were only two tills exposed in the cut; the lower till was assigned to the Illinoian glaciation because it was the next till below the Wisconsinan upper till. Richard P. Goldthwait and students from The Ohio State University (some of whom are probably on this trip) studied the exposure for over 30 years and references to this site appear in many of his publications. Goldthwait led part of the 1965 INQUA field trip to the site; the field guide for the trip (Goldthwait and others, 1965) included the often cited cross section reproduced here as figure 1.2. Early radiocarbon dates mentioned in the INQUA field guide include: 46,600 ± 2,000 years B.P. (GrN-3219) from wood in the Lockbourne Outwash, >53,000 years B.P. (GrN-4398) from wood in the Gahanna Till east of this cut near U.S. Rte. 40, and 23,000 ± 850 years B.P. (no lab number) for wood from the Wisconsinan till in a nearby farm well. Goldthwait also divided the Wisconsinan till into the "brown till" and the "middle blue till." Dreimanis and Goldthwait (1973) assigned the Gahanna Till to the early Wisconsinan Altonian Substage and thought that it was deposited between 50,000 and 60,000 years ago. Goldthwait (1992) reviewed his research and significantly changed his interpretation of the "Lockbourne Outwash" at the Gahanna cut. He determined that the outwash gravels were too high to be correlated with the Lockbourne Outwash as defined by Kempton and Goldthwait (1959) and that the clast lithology contains Berea Sandstone from an eastern source. He reinterpreted the gravels to have been deposited by a middle Wisconsinan alluvial fan built over eroded Gahanna Till. Goldthwait (1992) still thought that the Gahanna Till was deposited by an early Wisconsinan glaciation.

This meander of Rocky Fork continues to alter the exposure just as it had for the 30 years during which Goldthwait and his classes studied it. Over the years, discontinuous sand lenses and a striated boulder pavement have appeared at the contact between the "brown till" and the "middle blue till" (Goldthwait, 1992). In addition, a rusty-brown zone of clay enrichment (paleosol?) appeared to be developed in the underlying gravel. The origin of this zone and similar zones in southwestern Ohio and southeastern Indiana were debated by Gooding and Goldthwait in the 1950's and 1960's (Goldthwait, 1992). The degree of exposure at this stop varies with the season, amount of frost wedging during the winter, stream flow, meander migration, and degree of mass wasting. We may be able to find some silt lenses between the upper tills and possibly the boulder pavement, but the zone of clay enrichment has not been seen for many years.

Section description and discussion

Interpretation of the number of tills and their ages has changed over the years as different workers have examined this cut. Two (Stauffer and others, 1911) to as many as five (Fernandez and others, 1988) till units have been identi-

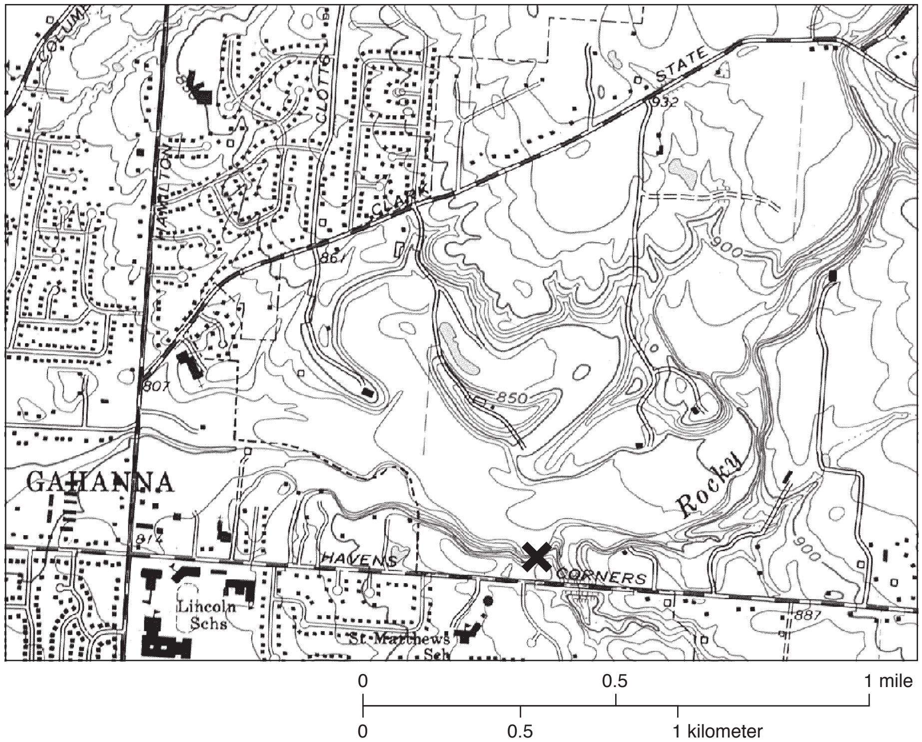

FIGURE 1.1.—Portion of U.S. Geological Survey New Albany 7.5-minute quadrangle showing location of Rocky Fork exposure (Stop 1).

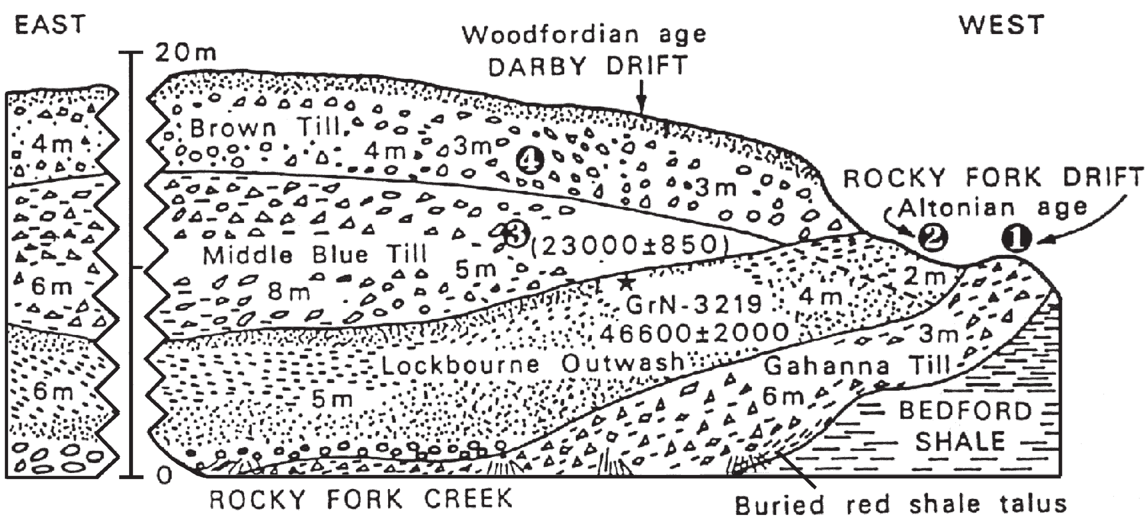

FIGURE 1.2.—Diagram of stratigraphic sequence at Rocky Fork exposure in Gahanna (from Goldthwait, 1965). The following description is from Goldthwait (1992): "The sandy gravel (2) was interpreted then as Lockbourne outwash, named from widespread outcrops to the right (west) and lower down under till plains from Columbus (south). The ^{14}C age in layer 3, Middle Blue till, came from wood drilled out of a nearby farm well. It is one of many 21,000 to 23,000 yr B.P. ages found in till of this mid-lobe (Scioto)."

Elevation of base of section: 253 meters (830 feet) • Height of section: 16.5 meters
See figure 6 for explanation of lithofacies abbreviations

Depth (meters)	Description
Holocene Series	
Colluvium	
0.00-1.00	10YR 5/4, yellowish-brown, friable, leached, diamicton (Dmm) containing large angular sandstone fragments.
Pleistocene Series, Wisconsinan Stage	
Darby Till	
1.00-3.20	10YR 5/4, yellowish-brown, firm to very firm, blocky to platy, calcareous diamictons (Dmm and Dms).
3.20-5.20	10YR 5/4, yellowish-brown, firm to very firm, blocky to platy, calcareous diamicton (Dmm) separated from underlying unit by a stone line.
Caesar Till	
5.20-7.15	10YR 3/2, very dark grayish brown, platy, friable to firm, calcareous diamicton (Dms) containing large pebbles and having sharp contact with the underlying unit.
7.15-9.00	5Y 3/2, dark-olive-gray, firm, blocky, stony, calcareous diamicton (Dmm and Dmm(s)). Underlying gravel is sheared into lower part of diamicton.
Gravels ("Lockbourne Outwash" of Goldthwait, 1992)	
9.00-10.10	10YR 5/4, yellowish-brown, poorly sorted gravel (Gms).
Pleistocene Series, Illinoian Stage	
Gahanna Till	
10.10-12.80	10YR 3/2, very dark grayish brown, firm, blocky, calcareous diamicton (Dmm) containing chert pebbles and shale granules.
12.80-14.75	5Y 3/2, dark-olive-gray, firm, blocky, calcareous diamicton (Dmm(s)) containing shale pebbles. Underlying gravel is sheared into diamicton.
Gravel	
14.75-15.75	10YR 5/4, yellowish-brown, loose gravel (Gms).
15.75-16.50	Covered to stream.

fied. Most workers agree that there is one till beneath the gravel near the base of the cut, but the interpretation of the number of tills above the gravel has varied. Goldthwait and others (1965) reported two tills above the gravel and informally referred to them as the "brown till," having a west-northwest source, and the "middle blue till," derived from a north-northeast source. This informal designation survived over the years until Weatherington (1978), after consulting with Goldthwait, correlated the "brown till" to the Darby Till and the "middle blue till" to the Caesar Till in her M.S. thesis. Taylor and Faure (1982) continued to use the informal units and collected samples at the site to use Rb-Sr dating to determine the age of the feldspars in the till and thus the provenance of the tills. They also analyzed the pebble content of these units. They found major discontinuities in pebble lithology within both the "brown till" and the "middle blue till" and interpreted these discontinuities to be boundaries between lodgement and ablation tills. This separation within each till was also reflected in the Rb-Sr ratios. There was no systematic variation among the provenance dates, indicating that the tills contained a heterogeneous mixture of rocks from the Grenville and Superior Provinces of the Canadian Shield (Taylor and Faure, 1982).

The separation of each of the upper tills into two subunits was further explored by Ohio State students, who discovered a stone line within the "brown till" and noted physical and lithologic differences within both tills. In 1992, Stan Totten noted these differences during his reconnaissance survey of

Licking County, and sampled the outcrop soon after. There is more clay in the upper diamictons within the “brown till” (hereafter referred to as the Darby Till) than in the lower diamicton (fig. 1.3), but their fine-carbonate contents and clay mineralogy are statistically inseparable (table 1.1). There is a similar change in texture within the “middle blue till” (hereafter referred to as the Caesar Till), but again the diamictons within this till cannot be separated by their fine-carbonate contents or clay mineralogy. The variations in calcite and dolomite within the diamictons of the Darby and Caesar Tills support the observation of compositional differences by Taylor and Faure (1982). The lower diamicton of each of these tills was probably deposited in a subglacial environment by meltout or by lodgement, whereas the upper diamicton of each of these tills may have been deposited by supraglacial meltout.

The age assignment and name of the lowest till in the Rocky Fork cut at Gahanna has changed several times over the last century. Stauffer and others (1911) assigned this till to the Illinoian glaciation, whereas Goldthwait classified it as early Wisconsinan in age. Szabo and Totten (1995), citing lack of evidence for an early Wisconsinan glaciation in Ohio, assigned this till to the Illinoian glaciation and placed it stratigraphically below the Millbrook Till on the basis of field evidence in Licking and adjacent counties. Goldthwait and others (1965) named this till the Gahanna Till, but Taylor and Faure (1982) and Fernandez and others (1988) referred to this till as the Rocky Fork Till. Fullerton (1986) referred to this till as either the Gahanna Till or the Rocky Fork Till and noted that there were multiple units of this till, which we will see at Stop 2. Fullerton also mentioned that the type section for this till had never been formally described. Szabo and Totten (1995) formally described the type section and named this till the Gahanna Till because of the abundance of streams named Rocky Fork in central and southern Ohio.

Taylor and Faure (1982) did not find any lithologic discontinuities within the Gahanna Till, but less than 2 meters of till was exposed at their sampling location. There is over 4 meters of till exposed in the section sampled for this study (fig. 1.3), and the till is divided into two diamictons. The lower diamicton contains pods and streaks of gravel which have been sheared upward from the underlying gravel. This diamicton has a fine-carbonate content similar to those of the Darby and Caesar Tills, but its clay mineralogy consists of more kaolinite and chlorite (lower DI ratio) than those of the younger tills. The older tills on the Allegheny Plateau generally contain more kaolinite and chlorite than those in the Central Lowlands and reflect the differences in bedrock between these physiographic provinces (Totten and Szabo, 1987). The upper diamicton of the Gahanna Till is slightly sandier but contains significantly more fine carbonate than the lower diamicton (fig. 1.3; table 1.1). Although the average DI ratios of the diamictons are the same, the upper diamicton

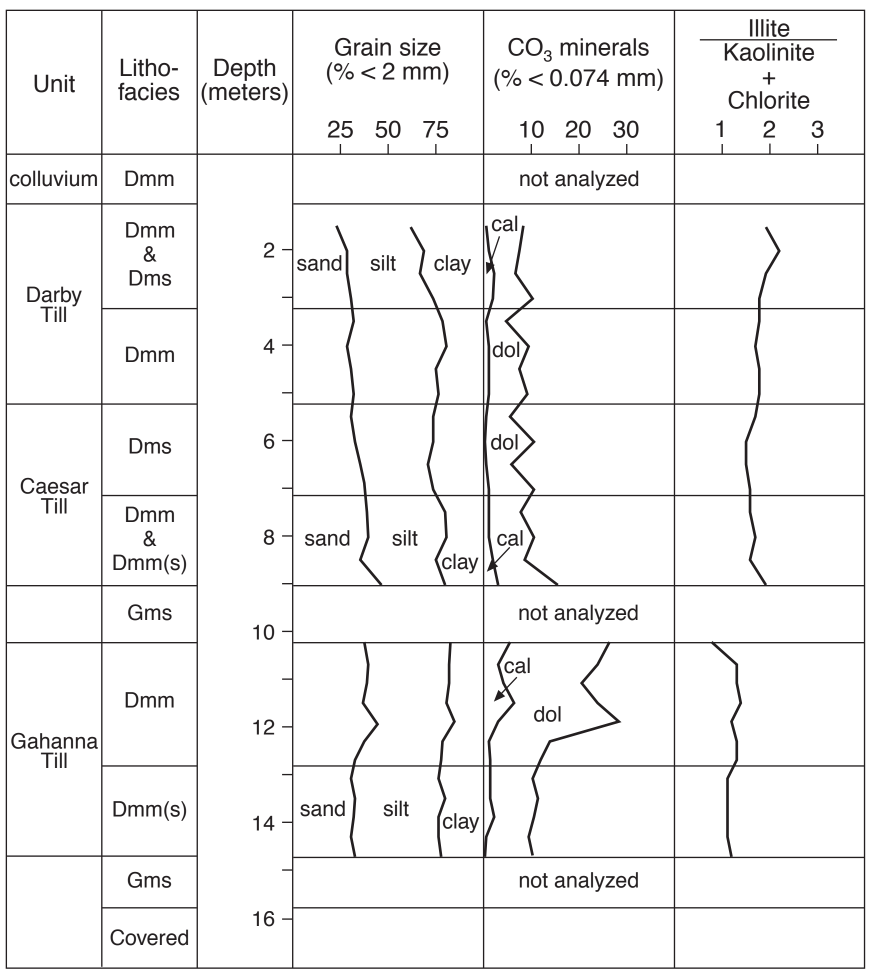

FIGURE 1.3.—Summary of laboratory analyses of units at Rocky Fork exposure at Gahanna (Stop 1). See figure 6 for explanation of lithofacies.

TABLE 1.1.—*Summary of laboratory analyses*[1] *of diamictons at the Rocky Fork exposure in Gahanna*

Unit[2]	sand	silt	clay	cal	dol	total carb	DI
Darby Till							
Dmm & Dms							
x	28	40	32	1.7	6.7	8.3	2.0
SD	3	2	5	0.8	1.6	1.6	0.2
n	4	4	4	4	4	4	4
Dmm							
x	31	47	22	1.2	6.6	7.8	1.8
SD	1	4	3	0.3	2.0	2.1	0.1
n	4	4	4	4	4	4	4
Caesar Till							
Dms							
x	35	39	27	0.8	7.6	8.4	1.6
SD	3	4	2	0.4	2.8	2.7	0.1
n	4	4	4	4	4	4	4
Dmm & Dmm(s)							
x	41	39	21	2.0	8.8	10.8	1.7
SD	5	4	3	1.0	2.6	3.4	0.1
n	4	4	4	4	4	4	4
Gahanna Till							
Dmm							
x	40	42	17	4.6	18.5	23.1	1.2
SD	3	2	2	1.4	2.5	2.4	0.2
n	5	5	5	5	5	5	5
Dmm & Dmm(s)							
x	33	45	22	1.4	9.8	11.2	1.2
SD	2	2	1	0.6	1.4	1.4	0.1
n	7	7	7	7	7	7	7

[1]x = mean, SD = standard deviation, n = number of samples, cal = calcite, dol = dolomite, carb = carbonate, DI = diffraction intensity ratio.
[2]See figure 6 for explanation of lithofacies abbreviations.

is more variable. Some sand-filled joints of undetermined origin are found in the upper diamicton (Fernandez and others, 1988). The lower diamicton contains fewer carbonate and crystalline rock fragments in the 1-2 mm fraction than the upper diamicton (table 1.2). The lower diamicton was deposited subglacially by lodgement. The upper diamicton contains significantly more carbonate and crystalline rock fragments, which were probably transported englacially and deposited by supraglacial meltout. Therefore, diamictons within each till in the Gahanna cut reflect subglacial and supraglacial environments of deposition.

Because this cut is eroding at the rate of 1 to 2 meters/year (Goldthwait, 1992), the exposed thicknesses and elevations of lithologic units vary and some pinch out altogether. The uppermost unit illustrated in this study is a diamicton interpreted to be colluvium. Ian Whillans and his students at Ohio State have also found silt (loess?) on top of the section. The gravel between the Caesar and Gahanna Tills (fig. 1.2), originally interpreted as "Lockbourne Outwash," is variable across the outcrop. Rounded boulders of Berea Sandstone, imbricated east to west, were exposed at the eastern end of the cut after a flood (Goldthwait, 1992). During the summer of 1992, Stan Totten found the following sequence of sediments beneath the Gahanna Till at the eastern end of the cut: 2 meters of cross-bedded brown gravel overlying 1 meter of clean, brown to gray sand deposited on at least 1 meter of gray gravel. The Rocky Fork cut at Gahanna is constantly changing. Ongoing observation, sampling, and analysis will help us decipher its complex story.

TABLE 1.2.—*Composition of the 1-2 mm fraction of the Gahanna Till*

Unit[1]	carbonate	clastic	crystalline
Dmm			
x	22	67	11
SD	3	4	1
n	5	5	5
Dmm(s)			
x	16	77	7
SD	2	2	1
n	7	7	7

[1]x = mean, SD = standard deviation, n = number of samples. See figure 6 for explanation of lithofacies abbreviations.

STOP 2, MOUNTS FARM EXPOSURES ALONG LOBDELL CREEK

Lobdell Creek to the north of Alexandria and Moots Run to the south have incised into the Wisconsinan glacial surfaces of west-central Licking County. They both flow on bedrock in numerous reaches in their lower courses. Bedrock is exposed along both channel banks at several locations along these and other similar-sized streams in the Licking River drainage, suggesting active channel incision in recent time. The odd, arcuate valley-plan forms and coincident confluences of Lobdell Creek and Moots Run with Raccoon Creek might reflect a late-glacial ice margin along a lobed, topographically controlled ice front. Lending topographic support to this interpretation is the fact that the highest land in the county, a WNW-ESE-trending upland at elevations of 395 to 410 meters (1,300-1,350 feet), lies 1.2 miles (2 km) to the northeast of Lobdell Creek and has very hummocky topography along its southwest flank, and there is a similar-trending broad upland at elevations of 365-380 meters (1,200-1,250 feet) immediately to the south of Moots Run.

Forsyth (1966) indicated a soil boundary and discontinuous end-moraine features along a lobelike north-south line in the west-central portion of the county (and through Alexandria) which she attributed to the margin of a late-glacial readvance. She correlated this margin with the Centerburg-Mt. Liberty soils break to the north in Knox County (Forsyth, 1961). The Quaternary map of Goldthwait and Pavey (1993) shows both early and late Woodfordian moraines in this area and the limit of the late Woodfordian advance in this general vicinity. Detailed mapping of possible ice-margin depositional features has been insufficient to ascertain the form of the ice front along the eastern margin of the Scioto lobe at various periods during the late Wisconsinan. The long, arcuate moraine features typical of the till plains of central and western Ohio are not present in the hilly glaciated edge of the Allegheny Plateau.

The two Mounts Farm sections are 1.1 miles (1.8 km) north of Alexandria and about 200 meters east of Mounts Road (fig. 2.1) in St. Albans Township, Licking County, Ohio. The Mounts Farm south section was measured in June 1992 by Stan Totten. A large slump in the center of the cut sometime prior to the fall of 1996 shifted Lobdell Creek away from the base of the cut and allowed much of it to stabilize and vegetate. We examined the Mounts Farm north section in the summer of 1997, and Tod Frolking and Shanan Peters measured and sampled it that same summer. We have included data from each section so that they may be compared and used to suggest conditions along the ice front.

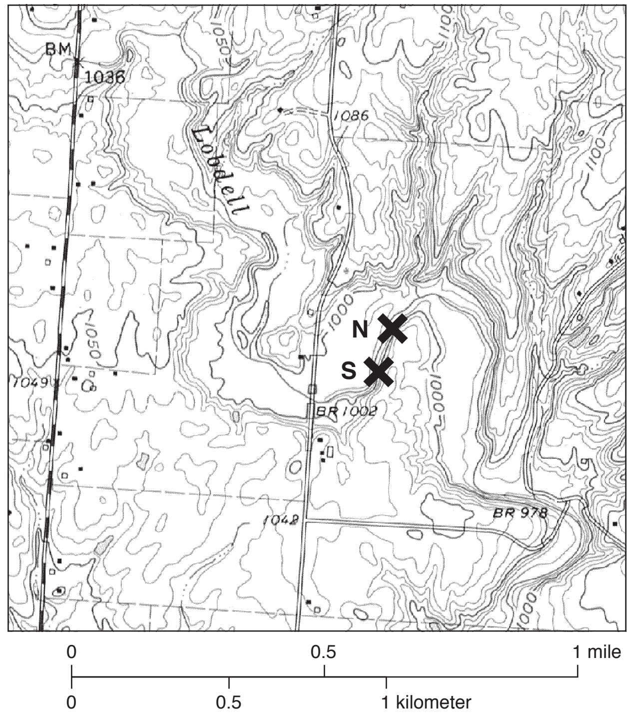

FIGURE 2.1.—Portion of U.S. Geological Survey Granville 7.5-minute quadrangle showing the location of the Mounts Farm north and south sections along lower Lobdell Creek (Stop 2).

Description and discussion of Mounts Farm south section

by John Szabo

The south section described by Totten in 1992 (fig. 2.2) displayed diamictons and gravels probably deposited along an ice margin during both the Wisconsinan and Illinoian advances. The Wisconsinan units represent two advances

Elevation of the base of the section: 314 meters (1,030 feet) • Height of the section: 16 meters

Depth (meters)	Description
Pleistocene Series, Wisconsinan Stage	
Loess	
0.00-0.20	10YR 4/3, dark-brown, loose, friable silt loam having a variable thickness.
Hayesville Till? (Navarre Till)	
0.20-0.80	10YR 4/3, dark-brown, to 5 YR 5/3, reddish-brown, mixture of clay, silt, sand, and gravel having a lenticular to irregular shape. Matrix is clay rich.
0.80-2.33	10YR 4/3, dark-brown, firm, blocky till having few pebbles, and a 7.5-cm-thick zone of secondary carbonate in its upper part. Unit is calcareous below this zone and has a silt band containing a few stones at its base.
Navarre Till	
2.33-3.80	10YR 4/4, dark-yellowish-brown, firm, platy, sandy, pebbly, calcareous till.

Pleistocene Series, Illinoian Stage

Gahanna Till

3.80-4.60	10YR 5/3, brown, sand and gravel that pinches out to the west where the overlying Navarre Till lies directly on Illinoian till.
4.60-7.60	10YR 3/2, dark-gray, firm, blocky, calcareous, pebbly till.
7.60-11.40	10YR 3/2, dark-gray, mixture of firm, blocky, calcareous, pebbly till containing many sand and gravel lenses.
11.40-13.60	10YR 3/2, dark-gray, firm, blocky, calcareous, pebbly till. Lower 5 cm oxidized 10 YR 5/4, yellowish brown, and has a sharp contact with the underlying unit.
13.60-13.68	10YR 6/8, brownish-yellow, firm, calcareous, laminated fine sand, silt, and clay.
13.68-14.40	10YR 5/4, yellowish-brown, loose, coarse sand and gravel containing large angular clasts.
14.40-16.00	10YR 3/1, very dark gray, to 5 Y 3/2, dark-olive-gray, very firm, calcareous till. Upper 10 cm is oxidized 10 YR 5/4, yellowish brown.

into this part of the plateau. One sample of diamicton of the first advance contained 16 percent sand, 47 percent silt, and 37 percent clay; another contained 28 percent sand, 40 percent silt, and 32 percent clay. This diamicton resembled the Navarre Till of northeastern Ohio. The characteristics of the overlying diamicton—low sand content, secondary carbonate, blockiness, and sparse pebbles—were similar to the those of the Hayesville Till of the Central Lowlands. Although recent maps of the Ohio Geological Survey (Goldthwait and Pavey, 1993; Goldthwait and Van Horn, 1993) and work by Paris (1985) show the Powell Moraine as the limit of the post-Erie Interstade diamictons, Totten has found fine-grained diamictons beyond these limits (White, 1982). It is possible that these Wisconsinan diamictons represent the two pre-Erie Interstade advances found in western Licking County.

Multiple advances along an oscillating ice front during the Illinoian are represented by the sequence of diamictons and gravels in the lower three-fourths of the section. Totten thought that the diamictons and gravels between 3.8 and 13.6 meters (fig. 2.2) were part of the same package. The middle sequence of sediments consisted of diamictons that pinch out toward the northeast, suggestive of sediment flows off an ice margin. The sand and gravels are coarse, containing angular clasts, implying only a short transportation distance. The lowest part of the diamicton at 13.6 meters has a very sharp, horizontal contact with the underlying silt; Totten referred to this contact as a “glacial pavement.” The origin of the underlying laminated fine sand and silt is problematic. Were they deposited as loess or fluvially? These laminated sediments overlie a poorly sorted gravel containing channers of local rocks. The bottom of the section consists of a diamicton that resembles other diamictons overlying the laminated sediments. Were the fine sand and silt and the poorly sorted gravel derived from this diamicton or do they represent interstadial erosion and deposition? The coarse-to-medium-silt ratio of the laminated sediments is 0.43, whereas that of the lower diamicton is 0.26. Does this suggest that laminated deposits are derived from the diamicton?

Szabo and Totten (1994) correlated the Illinoian diamictons exposed at this cut and other nearby cuts to the diamicton exposed in the lower part of the Gahanna cut. Field characteristics and carbonate content suggest that the lower tills at both sites are the Gahanna Till (Szabo and Totten, 1995).

Description and discussion of Mounts Farm north section

by Tod Frolking

During the summer of 1997, the somewhat smaller northern exposure was partially cleared, described, and sampled (fig. 2.3). We can only hope that natural processes will help to clear more of the exposure by the time of this field trip. The general stratigraphy of the north and south sections appears to be similar. Each has upper and lower diamictons separated by a complex sequence of glaciofluvial deposits. There are, as well, many differences which reflect variations in depositional environments both laterally and temporally. Of particular significance are (1) bedrock is exposed immediately north of the north section, (2) a glaciofluvial sequence underlies the lower diamicton at the north end of the north section, (3) the upper silty diamicton is overlain by coarse debris flow and probable lag deposits, suggesting a supraglacial environment for at least some of the final depositional event.

Textural and mineralogical analyses were run on samples taken near the top, middle, and bottom of each diamicton where exposed in sampling columns II to V (fig. 2.3; table 2.1). The lower diamicton is calcareous throughout and is unoxidized (typically 2.5Y 4/2) except where adjacent to sand and gravel lenses. Textural variations of the lower diamicton show no systematic pattern vertically or laterally through the section. Lower diamicton samples do, however, show considerably less variation in carbonate content and DI vertically (within a sampling column) than laterally. For example, DI values for three samples from column III were

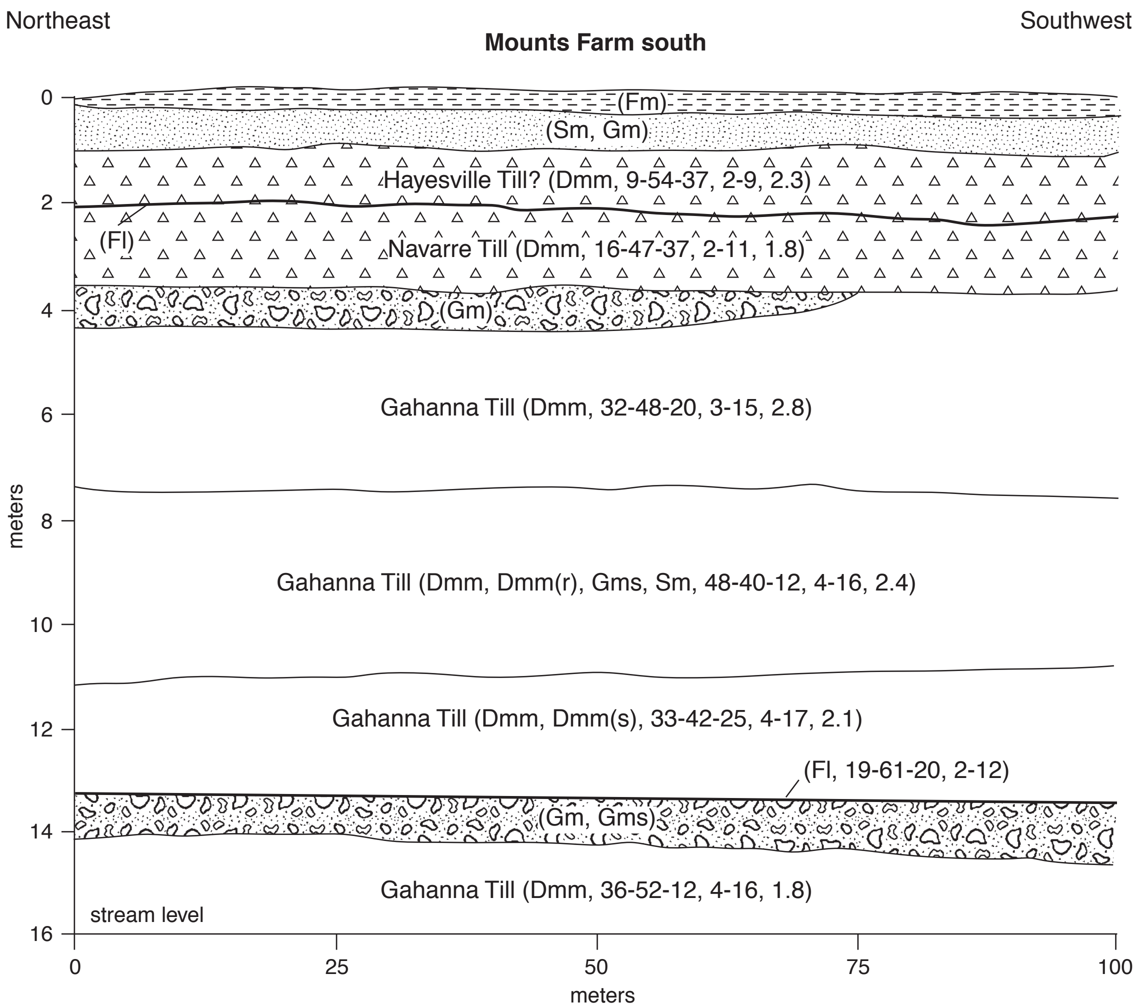

FIGURE 2.2.—Stratigraphy of Mounts Farm south section based on description by Stan Totten in 1992. Information in parentheses denotes lithofacies (see fig. 6 for explanation), percent sand-percent silt-percent clay, percent calcite-percent dolomite, and clastic/carbonate ratio. Vertical exaggeration approximately 5:1.

all well above the mean, whereas samples from all other columns fell below the mean. The dolomite content of three samples from column IV were all at least one standard deviation below the mean and lower than all but one other value. This tendency for greater lateral than vertical variability within the diamicton raises questions about glacial erosional, transport, and depositional processes and the reliability of correlating units based on spatially limited sampling.

The upper 1 to 2 meters of the upper diamicton is leached and the upper 3 meters is oxidized (typically 10YR 5/4). The uppermost two samples from columns II and III were leached of carbonates and therefore separated from the rest in table 2.1. The lack of any consistent lithologic or stratigraphic change at the oxidized/unoxidized boundary suggests that the boundary is just the oxidation front in the relatively impermeable diamicton. Similar brown zones in the diamicton stringer (column IV, fig. 2.3) and the upper portion of the lower diamicton adjacent to oxygen-bearing, permeable sand and gravel lenses support this conclusion.

Although the data are not subdivided in table 2.1, there are no obvious trends in texture or mineralogy either vertically or laterally within the upper diamicton. One somewhat more gravelly (26 percent) and clayey (32 percent) sample in the middle of the upper diamicton in column IV had significantly more total carbonates (52 percent) and the highest DI ratio (3.7) of the group and was an important contributor to the higher standard deviations in the upper diamicton relative to the lower diamicton. It is open for debate whether either the northern or southern exposure indicates two temporally distinct upper diamicton deposits.

The presence of sand and gravel stringers and lenses in both diamictons and the thin (<1 meter) diamicton layer bounded above and below by fluvial units suggest an englacial meltout origin for much of the material. A large, tabular limestone block within the gravel (column IV, fig. 2.3) immediately above the diamicton stringer favors englacial deposition as well. The cobbly diamicton having a sand and gravel matrix (top of column IV, fig. 2.3) suggests a debris flow (flow till). Any clear evidence of basal lodgement till such as fissility, shear zones, and strongly oriented or fractured clasts has escaped observation.

The fluviolacustrine deposits, which occupy about 50 percent of the exposure, have a strong glacial signature, that is, no fining-upward channel/point bar deposits indicative

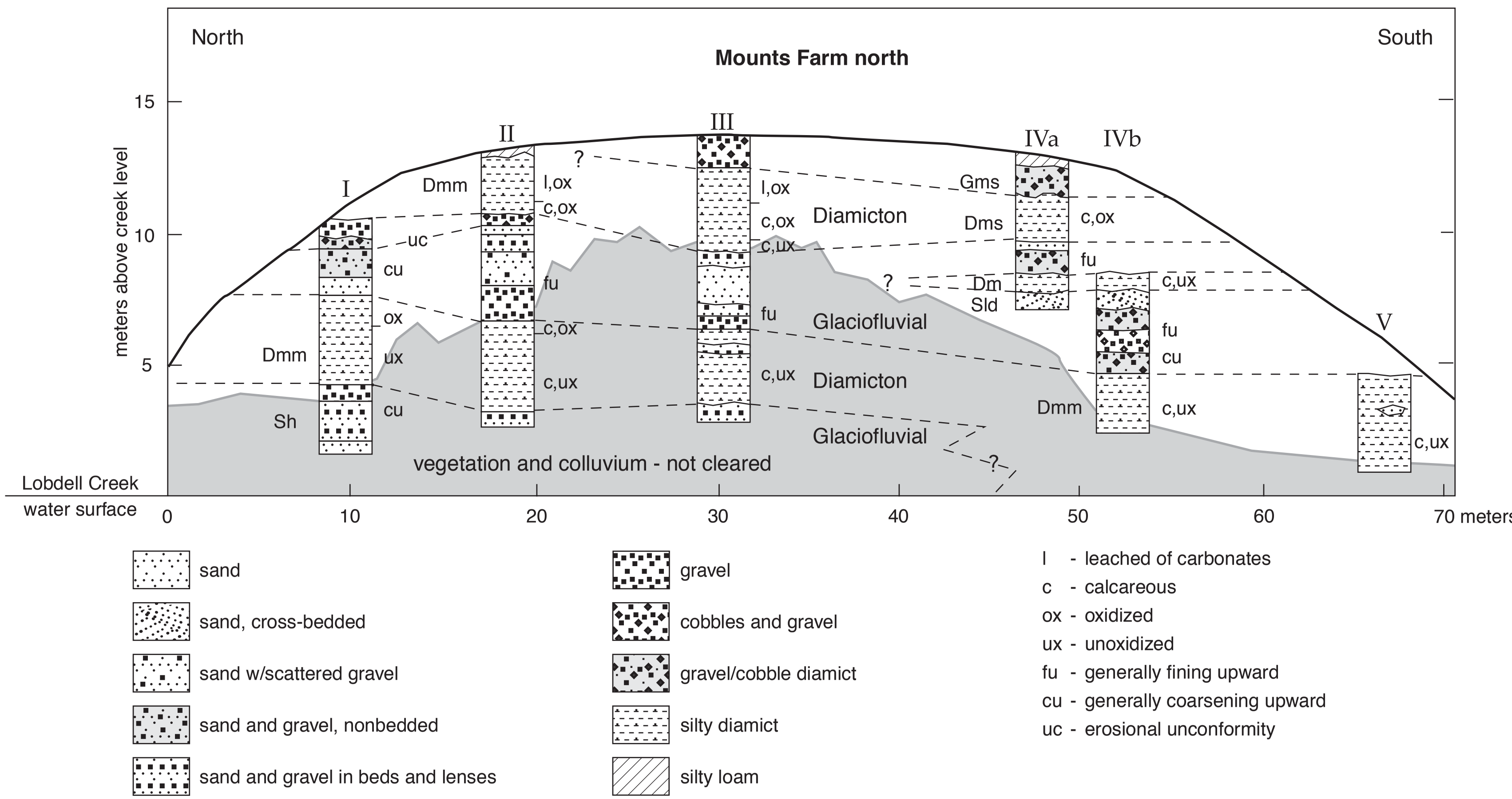

FIGURE 2.3.—Stratigraphy of Mounts Farm north section based on description of five sampling columns (I-V) during the summer of 1997. See figure 6 for explanation of lithofacies abbreviations. Vertical exaggeration 1.4:1.

TABLE 2.1.—Summary of laboratory analyses[1] of diamictons at Mounts Farm north section

Unit (no. of samples)	> 2mm (%)	fine fraction sand (%)	fine fraction silt (%)	fine fraction clay (%)	cal (%)	dol (%)	total carb (%)	DI
Weathered upper diamicton (2)	9.6	30	46	24	0	0.4	0.4	1.7
Upper diamicton (6)	16.4	31.7	45.5	22.8	2.6	22.7	25.3	3.0
SD	5.4	3.4	4.9	5.1	2.4	11.0	13.1	0.6
Diamicton lens (1)	27.8	35	45	20	3.3	19.3	22.6	1.6
Lower diamicton (11)	18.7	36.6	42.1	21.3	4.1	10.3	14.4	1.9
SD	2.9	2.2	7.5	7.3	0.6	5.4	5.1	0.9
Difference of means test	0.88	2.93	1.05	0.46	1.38	2.38	1.79	2.81
Upper vs. lower diamicton						(4.19)[2]	(3.57)[2]	
Significance	ns	0.05	ns	ns	ns	0.05	(0.05)[2]	0.05

[1]SD = standard deviation, cal = calcite, dol = dolomite, carb = carbonate, DI = diffraction intensity ratio, ns = not significant.
[2]Statistical values after deleting one upper diamicton sample that has very high dolomite content (44.9 percent).

of meandering channels are present. The sand deposits generally show laminar bedding suggestive of rhythmic sedimentation; gravel units generally lack depositional features beyond imbrication. The variable position of fining-upward zones (fu in columns II, III, and IV, fig. 2.3) and coarsening-upward zones (cu in columns I and IV, fig. 2.3) of laminar to tabular beds relative to diamicton units disallows the development of any simple depositional model for the fluvial materials relative to locations of nearby ice. The sand and gravel unit underlying the lower diamicton in the northern portion of the exposure appears to be linked to the lower diamicton. It is not known if other units underlie the lower diamicton at the southern portion of the north section or at the south section. Siltstone of the Raccoon Shale Member of the Cuyahoga Formation is exposed immediately downstream (north) of the north section, and calcareous gray diamicton directly overlies bedrock at several exposures farther downstream.

Interpretation of the glacial sequence

This location should allow for lively debate among lumpers and splitters. No paleosols are present, and all materials below the modern surficial leached zone are calcareous. The site stratigraphy alone gives little indication of the length of time over which these units were deposited. A few contacts show a clear truncation of the lower unit (uc in columns I and II, fig. 2.3) but give no indication of a significant time break. The data that show statistically significant differences between the upper and lower diamictons are percent sand, percent dolomite, percent total carbonate, and the DI ratio (table 2.1).

The low dolomite and total carbonate contents of the lower diamicton relative to the upper diamicton are contrary to the patterns observed at the Rocky Fork section at Gahanna and the Mounts Farm south section, where a distinguishing attribute of the lower diamictons (Illinoian) are their relatively high carbonate contents (table 1.1; fig. 2.2). In absolute terms, the dolomite and carbonate contents of samples of the lower diamicton at Mounts Farm north are on average lower than those for the lower diamicton at Mounts Farm south and the upper portion of the Gahanna Till at Rocky Fork. The lower DI ratios for the lower diamicton relative to the upper diamicton are similar to the pattern at Rocky Fork, although the values at Mounts Farm north tend to be higher. This relationship, however, is not found at Mounts Farm south. The variability within units and among sites speaks to the difficulties of till correlation and the need for detailed sampling at many locations.

Neither of the two most obvious interpretations of the Mounts Farm north section stratigraphy—(1) a basal Illinoian unit overlain by a single late Wisconsinan depositional package, or (2) wholly late Wisconsinan material deposited by either one complex or perhaps two distinct ice advances—sits well with the complex stratigraphies developed for much of the Scioto lobe (Dreimanis and Goldthwait, 1973; Quinn and Goldthwait, 1985). Although it seems clear that thick Illinoian diamicton deposits are present farther west (see figs. 6 and 9), Illinoian drift on the more dissected uplands and sideslopes in the central part of the county may be highly discontinuous. Several lines of evidence presented during this field trip will suggest significantly greater local and regional relief in post-Illinoian time compared to the Holocene. Thus, the present Illinoian drift cover could be highly variable, and there is the potential for stripping of Illinoian deposits prior to the advance of Wisconsinan ice.

STOP 3, WILDWOOD PARK/GRANVILLE WELL FIELD

by Tod Frolking

The well field for the village of Granville lies on the floodplain of Raccoon Creek immediately southeast of Wildwood Park (fig. 3.1). To find a suitable location for a new water well, Metcalf and Eddy, using Alliance Environmental's sonic coring truck, took four 35-meter continuous cores from test borings in the western portion of the well field in November 1995. Logs of the four cores (fig. 3.2), coupled with previous well logs and test wells in the northeastern portion of the well field, reveal a complex late-glacial stratigraphy. Discontinuous diamictons and sand/gravel units within the valley fill as well as the numerous kames and kame terraces in the area suggest deposition by stagnant ice.

Pilot hole 1 (fig. 3.2) is particularly significant for interpreting the valley's history. The core consists of overbank silt to very fine sand deposits which overlie a poorly drained,

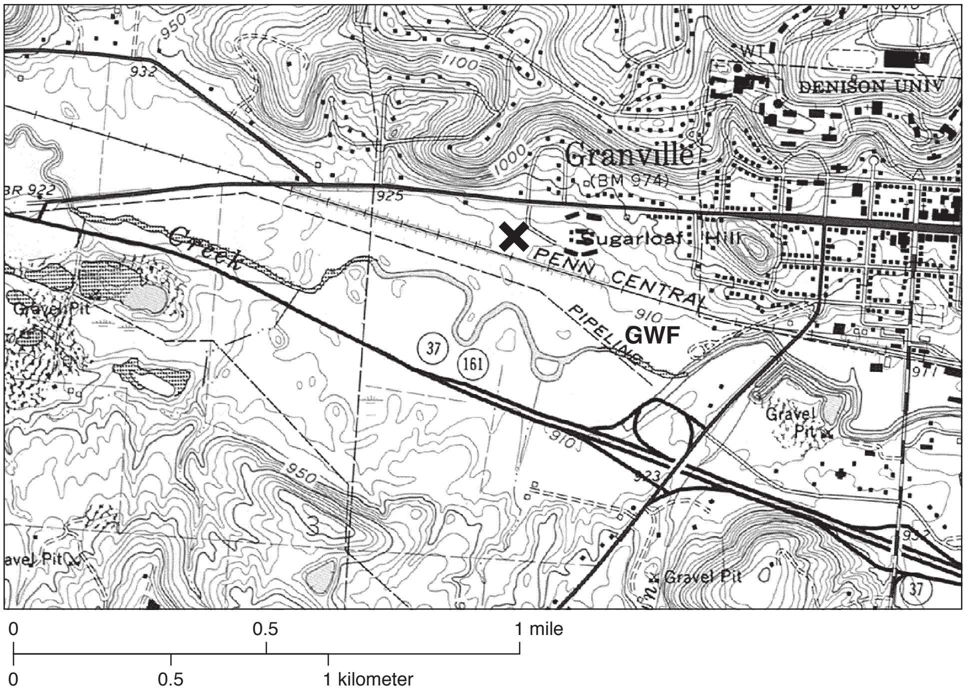

FIGURE 3.1—Portion of U.S. Geological Survey Granville 7.5-minute quadrangle showing the Raccoon Creek valley west of Granville and the locations of Stop 3 and the Granville well field (**GWF**).

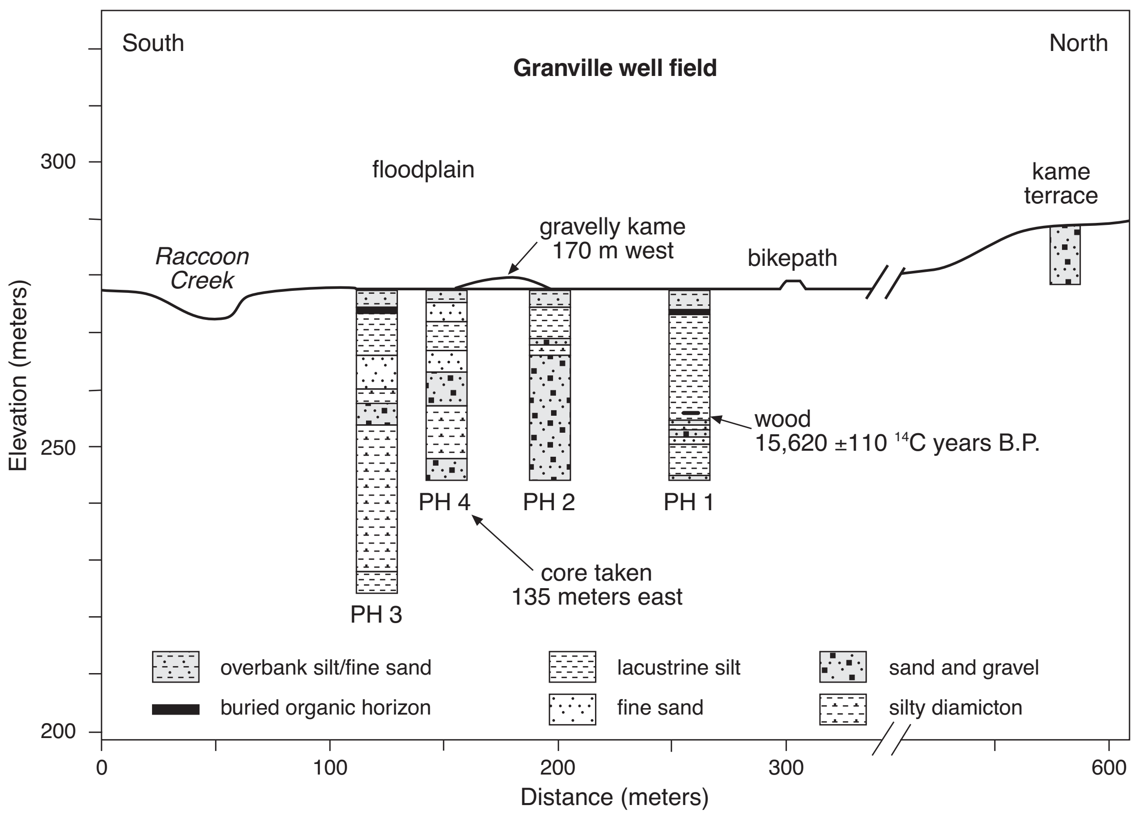

FIGURE 3.2.—Diagram of four pilot-hole (PH) logs in the Granville well field showing discontinuous subsurface glacial stratigraphy and postglacial lacustrine fill. Kame-terrace stratigraphy is based on foundation excavation and footslope pits. Vertical exaggeration 2.5:1.

organic-rich buried silty soil at a depth of 3.3 meters. Lacustrine silt extends down to about 22.5 meters, grading to fine sand, then sand and fine gravel at 23.5 meters. Mainly sand and silt zones containing some gravel extend down to 35 meters. Wood recovered at 22.2 meters dated to 15,620 ± 110 years B.P. (Beta-91907). This date corresponds to the Erie Interstade, when glacial ice was out of the Licking River basin. Following the wasting of stagnant, pre-Erie Interstade ice from the valley floor, a 20+-meter-deep lake occupied this site. Just 62 meters to the south (pilot hole 2), 2 to 3 meters of lacustrine sediments overlies 1+ meter of sandy gravel which overlies silty diamicton. Here the lake was more shallow. About 170 meters to the west, a kame rose 25 meters above the lake bottom and shows no lacustrine sediment on its crest. The modern floodplain hides a postglacial valley-bottom terrain of considerable relief. Up valley toward Alexandria, the floodplain has a very gentle gradient of 0.0011, and kames protrude here and there. Much of this area was probably occupied by postglacial lakes as well. Thus, much of the floodplain of this stretch of Raccoon Creek is not a surface of lateral planation following postglacial incision, but rather one of lacustrine deposition and subsequent overbank aggradation. The high terraces and kames flanking the valley are not erosional remnants of formerly more continuous depositional surfaces but are isolated ice-contact features that have been partially enveloped by valley-bottom sedimentation.

The stratigraphy at the Granville well field calls into question Goldthwait and Pavey's (1993) placement near Alexandria of the eastern limit of the last late Woodfordian ice advance into Licking County. Three possible explanations for the Granville stratigraphy are: (1) the last glacial advance reached the Granville area, (2) an older ice block remained in the valley at Granville during that last ice advance to Alexandria, or (3) the lake at Granville remained substantially unfilled with sediment during that last ice advance to Alexandria.

STOP 4, LOWER DRY CREEK

by Tod Frolking

This stream is aptly named because glacial outwash in the lower section of the valley has sufficient hydraulic conductivity to transmit Dry Creek's discharge as subsurface flow during low-flow periods. The flow of this stream is quite peaky, perhaps owing to the combination of broad areas of impermeable glaciolacustrine deposits upstream of the Dry Creek narrows and fairly steep terrain in the lower portion of the basin. Because of recent channel incision and instability, this site affords excellent exposures of late Wisconsinan outwash, the silty cap generally interpreted as loess, and Holocene soil development. The broad expanse of channels and bars is great for rock hunting—note exotic clasts of Precambrian tillite, anorthosite, diabase, quartzite, and granitic gneiss from the Huronian Supergroup and Grenville Province of the North Bay/Sudbury region of Ontario. Interesting rocks aside, one main focus of our stop here will be to examine changes in channel morphology induced by channel straightening and in-stream gravel mining downstream (fig. 4.1). Lower Dry Creek has been transformed from a meandering stream transporting a modest bedload to a steepened, multichannel system capable of transporting the coarsest components of the outwash valley fill.

Historical records and air photos indicate that rapid channel changes began in the 1940's. The excavation of gravel from terraces and the floodplain downstream began during that period. The removal of gravel directly from the channel, about 800 meters downstream from our entry point, increased to about 9,000 cubic meters per year in the 1960's. This removal effectively lowered the local base level of the stream. A steepened channel section was created which then migrated upstream. Apparently, the rate of lateral channel migration increased as the stream adjusted to the steepened channel gradient. Because cutbank erosion was endangering some residences and power lines, the channel was straightened in the 1960's (see abandoned meander, am, in fig. 4.1). This action, of course, steepened the channel gradient still further, and in turn increased the rate of incision and channel migration upstream. The former property owner (Mr. Butler) at our entry point estimated that the channel had incised 1.8 meters along his property between 1976 and 1985 (notes from a public hearing in 1986).

Burgess and Niple, Ltd. (1986) estimated that Dry Creek had eroded 11,000 cubic meters of sand and gravel per year from the adjacent Finney farm (equivalent to 600,000 metric tons of material) between 1962 and 1986. Over 5 acres of farmland was lost as the Big Bend meander expanded. The average rate of cutbank erosion at Big Bend has been 1.3 meters per year until recently. Over the past several years the channel has not actively eroded the cutbank at Big Bend. In 1982, landowner H. R. Finney (unpublished personal report) estimated that the bed of Dry Creek was at least 3 meters lower than in the 1940's. Note the stair-stepped form of the point bar, and progressively younger vegetation, on the inside of Big Bend meander. Also note that the meander, which was artificially cut off during the channel straightening in the 1960's, now lies well above the active channel.

Several reaches of lower Dry Creek were surveyed by Burgess and Niple, Ltd. (1986) and Jagucki (1987). They reported the channel slope in undisturbed reaches upstream to be about 0.0043. Average channel slope in the Big Bend meander was reported to be 0.050, and steep reaches in the braided section had gradients up to 0.090. One might question these values, as a gradient of 0.050 through the Big Bend section would yield a channel drop of at least 10 meters over the 200+-meter channel length; such a drop exceeds the height of the exposed high bank. Perhaps a zero was left out of both of these channel-gradient values. In any event, the disturbed section of Dry Creek had seen a significant increase in channel gradient. Because critical shear stress or tractive force is directly proportional to the energy slope of the stream reach, sediment-transport capacity and competence had increased dramatically as well.

In the fall of 1997, Frolking and his students surveyed a 1,500+-meter length of the Dry Creek channel, centered on the lower portion of the Big Bend, using transit and stadia rod to analyze channel-gradient adjustments since the earlier surveys. Over the surveyed length, the channel dropped 9.7 meters for an average gradient of 0.0062. This is significantly steeper than the gradient of 0.0037 that was surveyed at the Welsh Hills Road bridge 1 mile (1.6 km) up valley from Big Bend in 1997. The present channel gradients (fig. 4.1) are far less than those surveyed by Burgess and Niple, Ltd. (1986) and Jagucki (1987). Surveyed sections ranging from 140 to 230 meters in length had gradients ranging from 0.0041 to 0.0076. Two steep 50+-meter reaches had gradients of 0.011, still well below the values reported in the previous surveys. Gradients could be steeper over very short distances where the thalweg descends into channel

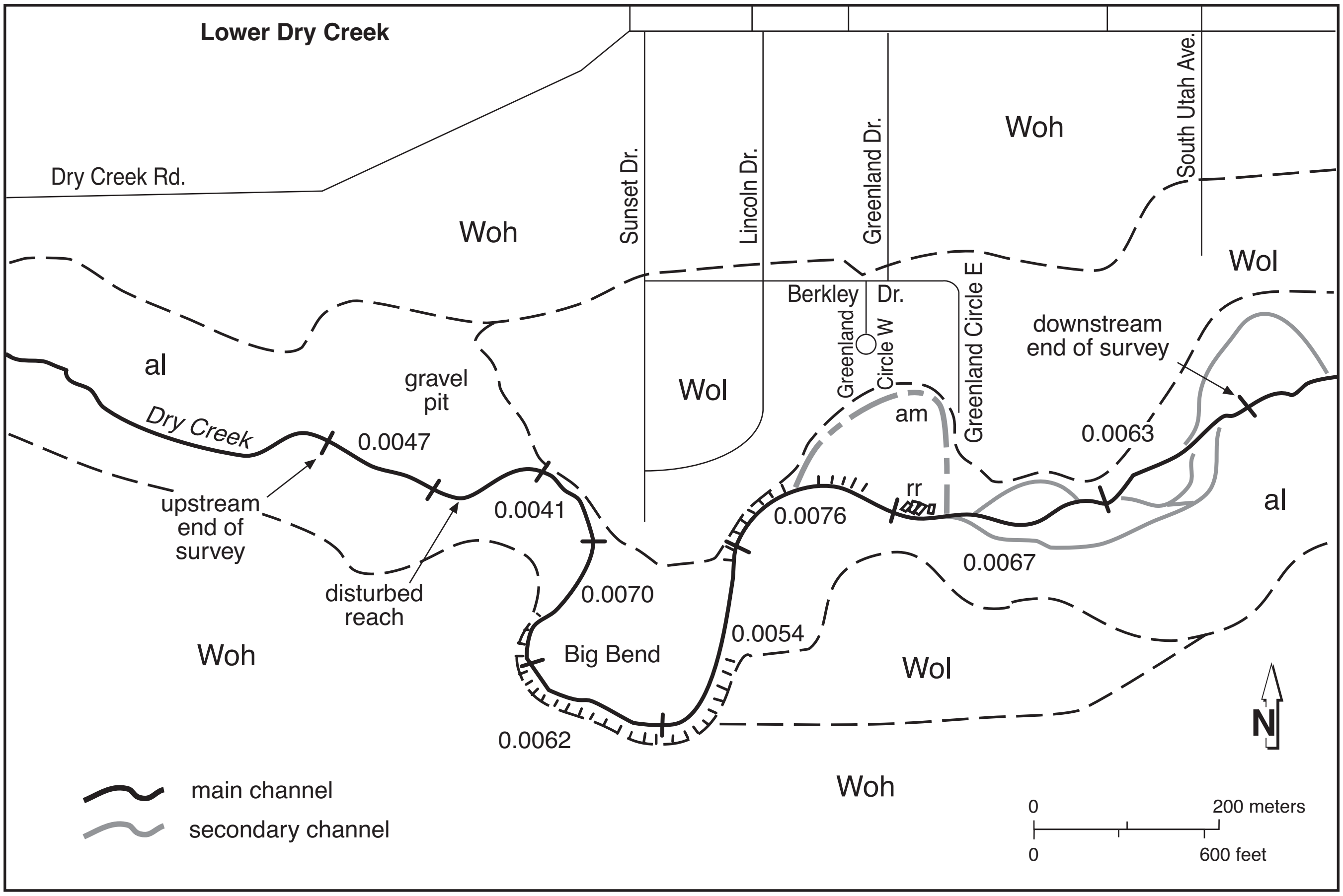

FIGURE 4.1.—Map of lower Dry Creek showing Wisconsinan outwash and modern alluvial surfaces. Hachures indicate steep slopes. Woh = high Wisconsinan terrace (Vanatta), Wol = low Wisconsinan terrace (Utica), al = Holocene alluvium, am = abandoned meander, rr = riprap (concrete slabs). Numbers indicate gradients of marked channel reaches based on 1997 survey.

troughs at meander bends or at constrictions, but these reflect localized energy conditions.

The channel does not show a specific upstream point to which the steepened, disturbed portion of the channel has advanced. Any knickpoint or "knickreach" that may have been migrating upstream has been mollified over time. Some recent mechanical reworking of the channel in the upper reaches of the surveyed section complicates this assessment. As upstream sections of the channel have steepened and transported more bedload downstream, downstream sections have begun to aggrade in a classic cut-and-fill sequence. According to landowners, the channel reach in the vicinity of the concrete slabs (rr on fig. 4.1) has aggraded as much as 3 meters since 1985. The 9-meter-long concrete slabs were put in then by the former landowner after several less massive riprap structures were carried downstream. The former problem of undercutting has shifted to one of aggradation, and flood waters now frequently reach the bank top and threaten to inundate the higher land.

STOP 5, SEVEN HILLS ROAD EXPOSURE

by Tod Frolking

This site (fig. 5.1) exposes the modern Alford silt loam soil (Typic Hapludalf, fine silty, mixed, mesic), an underlying Sangamon Geosol (as defined by Curry and Follmer, 1992) developed in a silty mixed zone over Illinoian outwash, and cryoturbation features developed in the Illinoian and Wisconsinan silty materials (fig. 5.2). This site was first excavated in 1985 in conjunction with mapping for the Licking County soil survey (Parkinson and others, 1992). Similar involution features were observed about 1.4 miles (2.3 km) to the east-southeast in exposures produced during construction of the eastward extension of Ohio Route 16 but were not described or analyzed in detail (Everett and others, 1971). Involutions also have been noted in a railroad cut 0.7 mile (1 km) to the south (Jones, 1959), but this site is presently heavily overgrown.

The soils and stratigraphy on the high Illinoian outwash surfaces to the east and south of the late Wisconsinan ice margin in Licking, Hocking, and Ross Counties support the recent interpretation that early Wisconsinan glaciers did not enter the Ohio River basin. Here at the Seven Hills Road site, late Wisconsinan Woodfordian loess directly overlies what in central Ohio has generally been termed a mixed zone, which in turn overlies Illinoian outwash. The mixed zone has the textural characteristics of an eluvial horizon of a well-developed Sangamonian paleosol. Norton (1981) also noted these characteristics for deposits in Perry County. Particularly note the very low fine-clay content of the mixed zone, which is indicative of eluvial conditions (fig. 5.3).

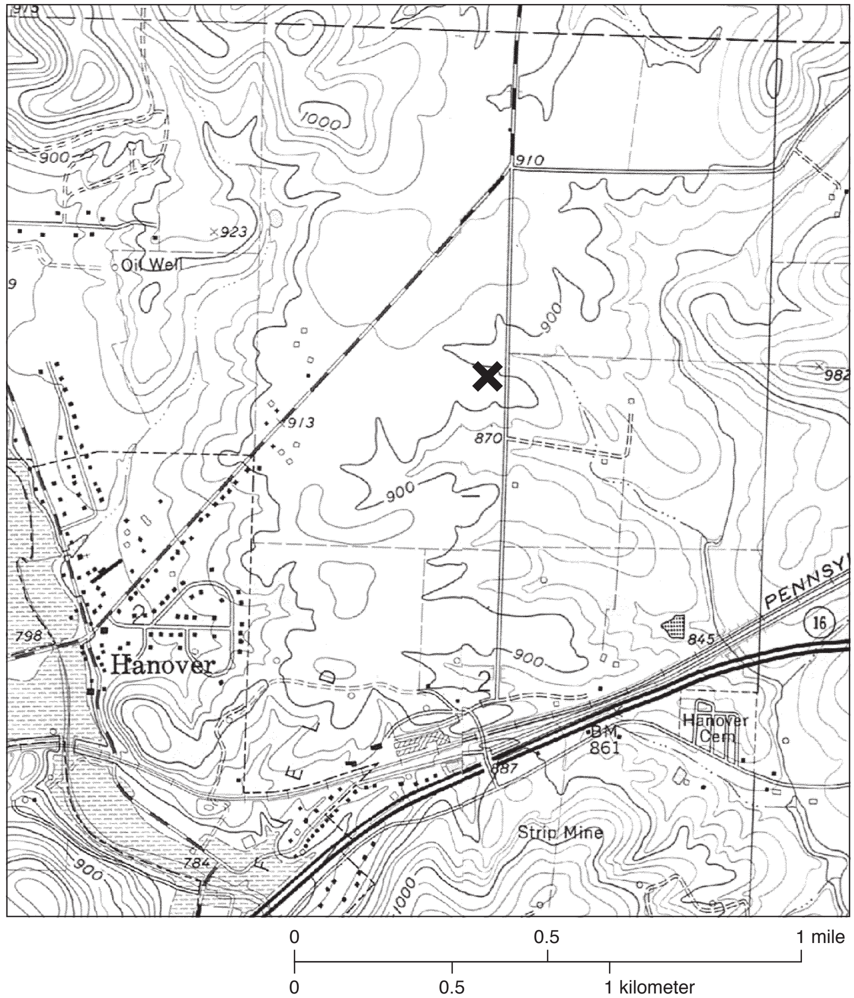

FIGURE 5.1.—Portion of U.S. Geological Survey Hanover and Toboso 7.5-minute quadrangles showing dissected Illinoian outwash surface and location of the Seven Hills Road exposure (Stop 5).

There is no indication of an intermediate period of loess fall between the late Illinoian and the late Wisconsinan; loess would be expected if early Wisconsinan ice and associated outwash had been present in the region. The advance of late Wisconsinan ice was heralded by accelerated colluviation, the formation of cryoturbation features, and loess deposition (Amba and others, 1990).

Unlike ice-wedge casts, which have not been recorded in this region, involutions are not diagnostic of a permafrost environment. Involutions may be due to cryostatic pressure associated with permafrost, to differential frost heave, or to a saturated zone composed of materials of different plastic and fluid properties under load (Williams and Smith, 1989). In the case of the Seven Hills site, the development of a thick saturated zone (>0.5 meter) for any significant time period is somewhat problematic without permafrost or at least a temporarily frozen subsurface layer. The underlying material is a well-drained gravelly loam which could cause at most a modest buildup of positive pore pressure in the overlying finer zone before water would enter the coarser pores of the gravelly loam and drain freely. Undoubtedly the development of an argillic B horizon during Sangamonian time reduced the conductivity of the upper gravelly zone somewhat but probably not to the degree to permit the depth of saturation needed for the involutions.

Although little work has been done on environmental conditions outside the eastern and southern margins of the Scioto lobe during the Woodfordian, conditions were, in all likelihood, similar to those in central Illinois described by Johnson (1990). In his careful and detailed analysis of ice-wedge casts and patterned ground in central Illinois, Johnson concluded that microclimatic conditions close to the Woodfordian ice margin were sufficiently rigorous to permit permafrost development. Ice-wedge casts were limited to recently deglaciated Woodfordian till plains south to a latitude of approximately 39°50', whereas patterned-ground features extended beyond the Woodfordian ice limit south to 38°30'. The Seven Hills site lies at 40°05', suggesting that if seasonal temperature regimes and snowfall conditions were similar to those proposed for Illinois, then permafrost could have developed during the glacial maximum. At that time the Wisconsinan ice front lay about 8 miles (13 km) to the west.

Konen (1995) observed polygonal patterned ground in Darke and Miami Counties in west-central Ohio. He believed that ice-wedge polygons developed in a zone of discontinuous to continuous permafrost when the ice front lay at the Union City and Mississinewa Moraines following the Erie Interstade. Palynological data suggest a narrow band of tundra adjacent to the ice front in that area between 16,000 and 15,000 years B.P. (Shane, 1976). Shane attributed this tundra zone to a steep climatic gradient in the immediate vicinity of the ice margin.

The location of the involutions in the mixed zone and the

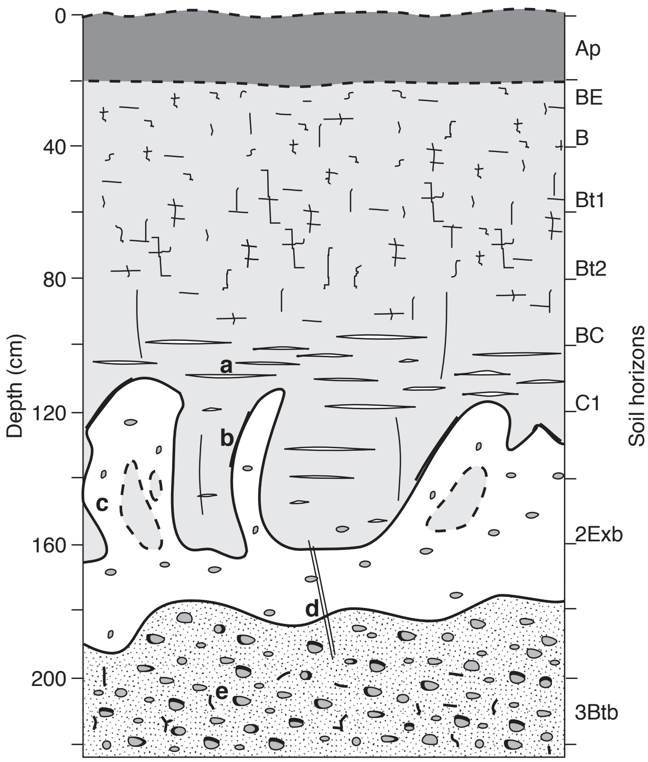

FIGURE 5.2.—Generalized diagram of the Seven Hills Road exposure, sampled and described in 1988. This site exposes late Wisconsinan loess, a mixed zone, and Illinoian outwash. The numerous features of Holocene and late Pleistocene soil development include **a**, low-chroma, clay-depleted laminar zones; **b**, illuvial clay films paralleling the loess/mixed zone boundary; **c**, involutions within the silty mixed zone and lower loess; **d**, bleached near-vertical planes within the brittle, fragic mixed zone; and **e**, moderate to thick 5YR 5/4 ferriargillans coating gravel and sand in the paleo Bt horizon.

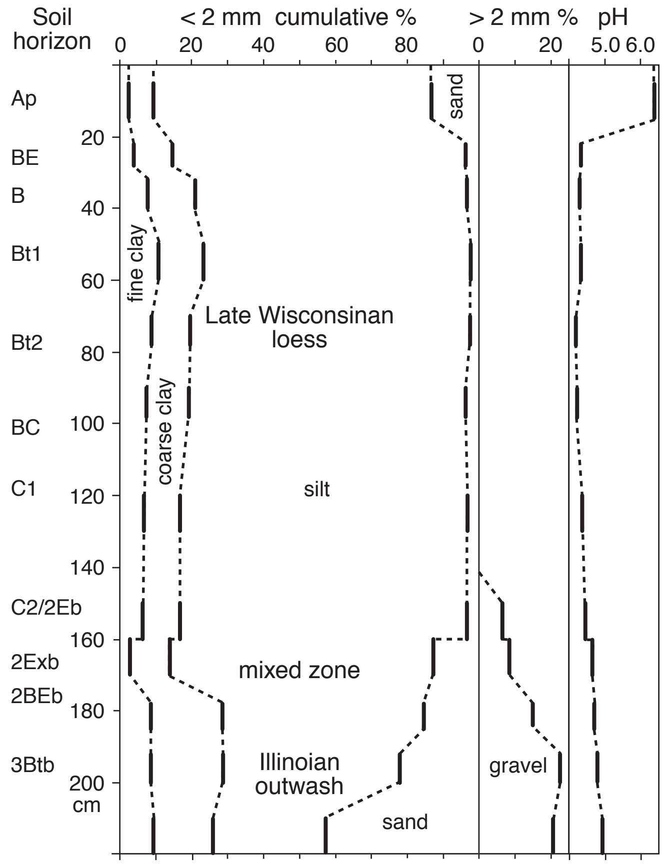

FIGURE 5.3.—Texture and pH data for the Seven Hills Road profile.

lower portion of the late Wisconsinan loess indicates that a significant portion (perhaps one-third) of the late Wisconsinan loess fall had occurred prior to their development. It does appear, as noted by Johnson (1990) in central Illinois, that the bulk of the loess fall occurred after the involutions had stabilized. In Licking County, the period of notable loess fall should have been roughly concurrent with the period of ice advances into the Licking River basin, perhaps 22,000 to 16,000 years B.P. The thin silt cap in Delaware County southeast of the Powell Moraine indicates that little loess accumulation would have occurred this far east after the Erie Interstade.

Khangarot (1969) made a detailed analysis of an Alford soil on the Illinoian outwash surface that we passed as we descended into Wilkins Run valley. Involutions were not present at that site, but there was interbedding of 2-3-cm-thick laminae of C-horizon loess and the underlying mixed zone material (a silty diamicton). Khangarot called this mixed silty zone, which underlies the Wisconsinan loess and overlies the Illinoian outwash, the intercalated zone because of this layering. This interlayering at the base of the Wisconsinan loess has been observed in cores at several locations on the Illinoian outwash plain and appears similar to banding observed at the base of the Peoria Loess in the Driftless Area of southwest Wisconsin. At one Wisconsin site, reworked loess was interlayered with cherty residual clay. This cherty clay could not have undergone any sort of fluvial or mass-wasting transport to cause the interlayering. Thus, the interlayering process must have occurred in the subsurface. The washing of silty loess into voids created by thawing ice lenses seems to be the most plausible explanation. Once initiated, the silty layers would grow in a positive feedback fashion because pore water readily migrates into the silty lenses, enhancing ice-lens growth. This intercalated zone between the loess and the mixed zone would not require permafrost conditions.

STOP 6, CARTNAL/POSTLE CUTBANK EXPOSURE ON ROCKY FORK

by Tod Frolking

Typical terrace stratigraphy

The Cartnal/Postle Rocky Fork site (figs. 6.1, 6.2) is the most extensive exposure of laminated lacustrine silt and overlying fluvial sand and gravel found in the lower reaches of tributaries to the Licking River. Observations at this site in the fall of 1995 led to a senior research project on the physicochemical properties and distribution of these lacustrine deposits in tributaries to the Licking River upstream from Black Hand Gorge (Pachell and Frolking, 1997). Active

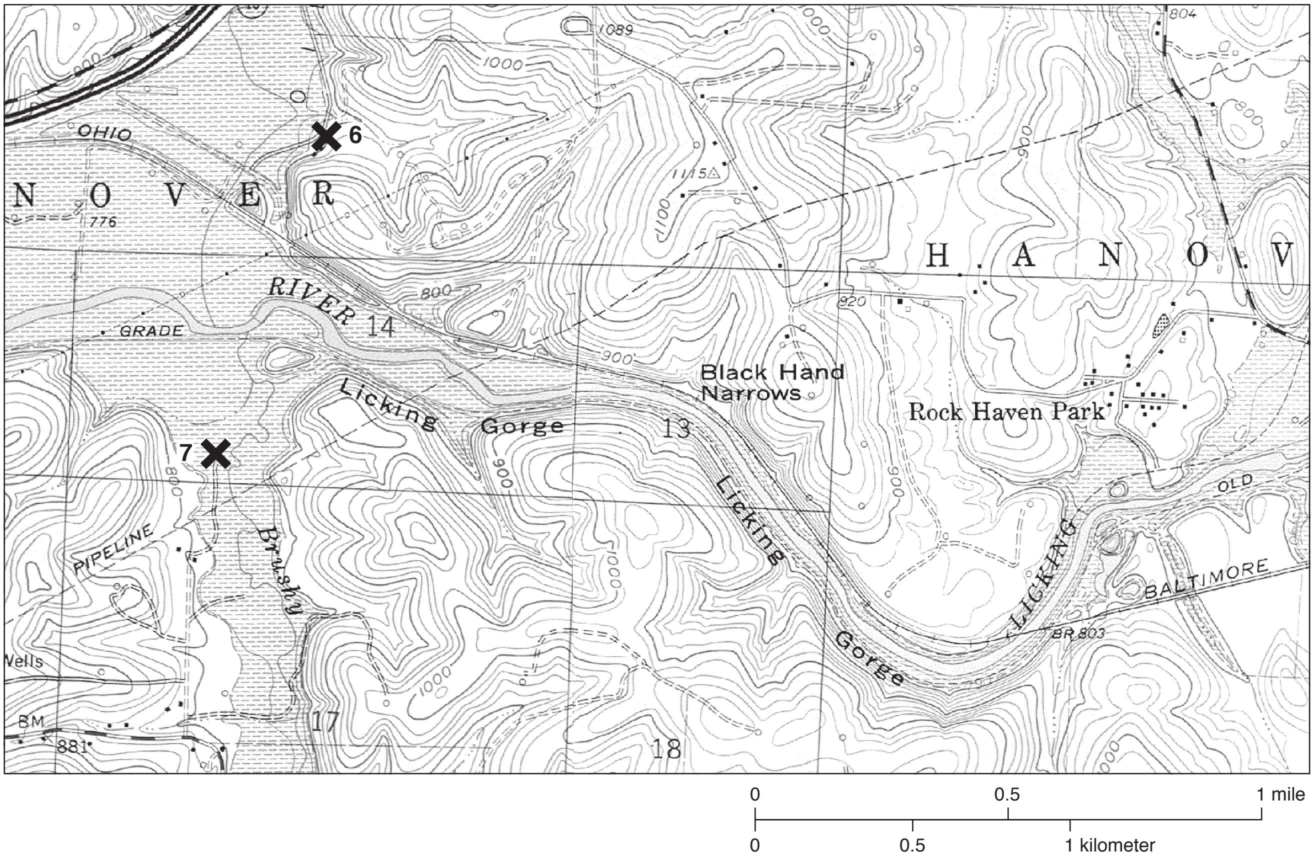

FIGURE 6.1.—Portion of U.S. Geological Survey Hanover and Toboso 7.5-minute quadrangles showing Black Hand Gorge area, including the location of the Cartnal/Postle exposure on lower Rocky Fork (Stop 6) and the starting point in lower Brushy Fork for the gorge tour (Stop 7).

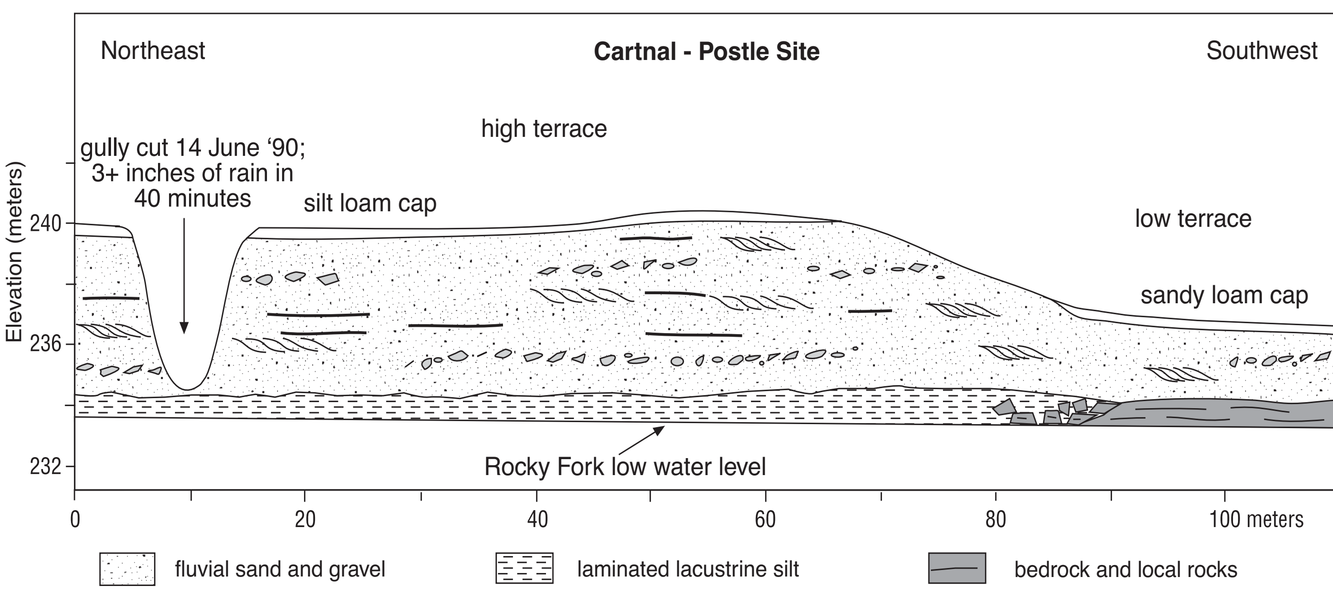

FIGURE 6.2.—Generalized diagram of the Cartnal/Postle cutbank exposure on lower Rocky Fork showing lacustrine silt, braided channel deposits, and silt/fine sand cap, which includes the modern soil. Vertical exaggeration 2.5:1.

lateral migration of Rocky Fork (0.5-1.0 meter/year) has kept this exposure relatively clean. However, because of a lack of high flows during 1997, the quality of the exposure has since deteriorated. The stratigraphy encountered here is similar to numerous other sites on the lower reaches of Rocky Fork, Little Claylick and Claylick Creeks, and Brushy Fork, suggesting a strong regional pattern of valley-bottom activity even though the valleys differ considerably in their links to Woodfordian ice and outwash.

High terraces have a cap of thin silt to very fine sand over a thick unit of sand and gravel. The fluvial sand and gravel units show poorly developed parallel bedding characteristic of shallow braided channels (Church and Gilbert, 1975). Fining-upward sequences or fine channel fills characteristic of actively meandering channels are not found in the high terrace deposits. No clear cut-and-fill structures or weathering zones within the sand and gravel have been observed. Thus, the bulk of the high terrace seems to represent a more or less continuous aggradational sequence. The braided character of channels must be due more to a heavy bedload generated by local erosion than to the direct input of glacial outwash. No exposures of the lacustrine silt have been noted along low terraces. These low terraces, which are typically 2.5 to 3.5 meters above low-flow water levels, are composed of sand and gravel down to at least the water level.

The lithology of the sand and gravel differs systematically from valley to valley. In lower Rocky Fork, which had no significant Wisconsinan glacial source of coarse material, the potential sources for the sand and gravel are local clastic bedrock units and the extensive Illinoian outwash fills found principally in the Wilkins Run valley (Forsyth, 1966). The upper portion of these gravel units are leached; hence, the reworked gravels present at the Cartnal/Postle site are leached. In the Claylick and Little Claylick basins, the gravels are generally calcareous. Sources for calcareous clasts include the abundant calcareous Illinoian diamicton and a drainage reversal into upper Claylick Creek (see Road Log, leg 8), which may have allowed Wisconsinan outwash to directly enter that basin. Gravels in the lower reaches of the unglaciated Brushy Fork basin are weakly calcareous and have a significant input of chert from the lower Pennsylvanian limestones and cherts that are exposed at higher elevations.

The contact between the sand and gravel and the underlying dense, cohesive, calcareous lacustrine silt is typically wavy and unconformable. The long contact exposed here is horizontal and has low-relief (10-cm) waves or undulations. Although laminations are truncated at the contact, few exposures reveal obvious channel cuts into the lacustrine sediment. Here, and at many localities, the upper zone of lacustrine silt in contact with overlying gravel is oxidized, making the laminations much easier to see. The lacustrine sediment is generally devoid of organics and visible shells or fragments. No exposures reveal any obvious indication of an unconformity in lacustrine sedimentation.

Interpretation of drainage history

Unfortunately, we have yet to obtain a core of a significant section (>2 meters) of the lacustrine sediments, so we have no direct indication of even a good minimum duration of the lacustrine episode. Suggestions are welcome on techniques for coring through unconsolidated gravel and into the dense lacustrine silt to obtain an undisturbed core. Similar lacustrine silt has been located at elevations ranging from a high of 255 meters (837 feet) at several locations to a low of 228 meters (748 feet) underlying the overbank and channel deposits on the modern Licking River floodplain. This range of elevations provides little information, as the lacustrine silt draped a valley-bottom landscape of unknown relief. Outside the floodplain and terrace environment, what is thought to be lacustrine silt and fine sand occurs up to an elevation of at least 256 meters (840 feet) in hollows flanking lower Rocky Fork valley. Calcareous sand containing gastropod shells, thought to represent a shoreline environment, lies at about 254 meters (833 feet) in a col to the east of Little Claylick valley. Thus, the lake had a maximum surface elevation of at least 256 meters (840 feet).

The laminated calcareous silt is thought to have resulted from deposition in a lake formed in front of glacial ice to the west in the Licking River valley. The lake level rose until it overtopped the col to the southeast and then drained to the east as Black Hand Gorge was cut (figs. 6.1, 7.1). This proglacial lake is tentatively named Glacial Lake Licking, drawn from Lake Licking, a name Tight (1894a) coined for what he thought was a more extensive post-Illinoian lake linked to the cutting of Black Hand Gorge. Several lines of evidence now support a late Wisconsinan age for at least the uppermost lacustrine sediments, those encountered in stream-bank exposures, and therefore for the final incision of Black Hand Gorge.

The calcareous, gastropod-rich sand in Little Claylick basin and the probable lacustrine sediments laid down upon dissected Illinoian deposits northeast of Hanover are shallow (<1 meter) and part of the modern soil profile. They lack any suggestion of a welded profile from more than one phase of pedogenesis. Thus, both of these deposits are interpreted as late Wisconsinan in age. One bank exposure in lower Rocky Fork reveals a coarsening-upward deltaic sequence. Fragments of nonwoody vegetal matter in laminated fine sands just below coarser fluvial deposits at an elevation of about 247 meters (810 feet) yielded a radiocarbon date of 21,660 ± 120 years B.P. (Beta-102848). If this date is reliable, the prograding fluvial deposits indicate the lake was lowering in the early Woodfordian, probably shortly after ice had advanced into central Licking County and blocked the westward drainage.

The fluvial gravels overlying the lacustrine deposits in the Licking River and tributary valleys represent an aggradational phase, and, therefore, initial channel erosion into the lacustrine deposits following drainage of the lake was probably minimal. Subsequent degradation, which resulted in the formation of the lower terrace surfaces, may reflect both an up-valley change in stream regimen and the continued incision into the Black Hand Gorge floor. Near the entrance to the gorge, the modern Licking River floodplain lies about 4 to 5 meters below adjacent high terrace surfaces and 2 to 3 meters below low terrace surfaces, again suggesting some combination of stream-regimen change associated with the shift to Holocene temperate conditions and further deepening of the gorge floor. As stated earlier, many tributary streams in the Licking River show evidence of relatively recent incision.

Assuming that the general sequence of events outlined above is correct, many questions remain. For example, the lacustrine sediments are now quite dense and cohesive. How quickly does this state develop and what impact does it have on the silt-gravel contact? Should there be some evidence of lacustrine fauna in the sediment or are proglacial lakes such as this typically free of shells? Although the main valley of the Licking River would have had a direct glacial fine-sediment source, this is not true of many of the tributary valleys. Thus the lacustrine sedimentation regime should speak to rates of both eolian input and hillslope erosion during the lacustrine period. Similarly, the braided channel deposits of the terraces must have a story to tell about conditions along the ice margin. Your observations and input are welcome.

STOP 7, UPPER BLACK HAND GORGE

by Tod Frolking

Given the time, weather, and initiative, we should walk into Black Hand Gorge as far as the approximate preglacial divide (figs. 6.1, 7.1). This hike will take us into the narrowest and steepest portion of the gorge, but we will not see many of the well-known historical features in the lower and more open section of the gorge. Topographic elements to observe include the two bedrock outliers at the entrance to the gorge, the distinct break in slope along the gorge sides at the contact of the massive Black Hand sandstone with the thinly bedded Berne conglomerate and the Byer sandstone, the wine-glass shape of hollows entering from the north and south, and the hanging valley of Owl Hollow. We can now only imagine the past, presettlement beauty of the gorge, when the arching branches of large trees on opposite banks intermingled over the river, presenting a gloomy, cavernous appearance during the summer months (Smucker, 1876).

Much of the early work on the evolution of Black Hand Gorge took place under the leadership of W. G. Tight about a century ago (1894a, 1894b). He recognized that the formation of the gorge was linked to the reversal of what he called the preglacial Newark River drainage. Without providing a specific time line, he linked the cutting of the gorge to a large postglacial lake dammed between the thick glacial deposits in the Newark River valley near Hanover (the valley fill at Stop 5) and the glacial deposits west of what is now Buckeye Lake in the South Fork Licking River valley. Prior to the formation of Black Hand Gorge, either glacial ice or the associated thick valley fill near Hanover had blocked and diverted the southwest drainage from the upper reaches of the Newark River system to the southeast, forming the modern Muskingum River.

Tight concluded that the simple form of the west portion of the gorge resulted from incision into the floor of a preglacial west-draining hollow as the col was gradually lowered. The opposite, east-draining hollow, however, was inundated and heavily scoured by the torrential flows as the impounded lake drained. Tight and his Denison students mapped numerous undercut bedrock slopes and channel remnants in the exit region of the gorge and concluded that there were three distinct channel positions as the gorge was incised (Tight, 1894b). Lacking another viable explanation, Tight called for a local glacial incursion from the north to force the channel into its present linear path where it cuts through several bedrock spurs by Toboso. He expanded his work on drainage changes to include much of the middle portion of the Appalachian Plateau in his seminal 1903 Professional Paper.

In Leverett's 1902 synthesis of the Pleistocene stratigraphy of the Erie and Ohio Basins, the glacial deposits in eastern Licking County were assigned to the Illinoian Stage. Subsequently, Denison geologists provided a range of landscape interpretations that were more directly linked to the region's glacial history. Contrary to most observers, Carney (1907b) believed the area east of Hanover had an easterly drainage prior to the earliest ice advance. On the other hand, Carney did state that the glacial lake east of Hanover might have been much more extensive than previously thought and that ice extended into Muskingum County to form morainal deposits north of Nashport.

Malcuit and Bork (1987) present a model of gorge evolution that follows the ideas of Dove (1960), among others. An extensive advance of Illinoian ice filled the pre-Illinoian Newark valley north of Hanover with sediment. A second advance blocked the Newark valley east of Newark and created what they termed Glacial Lake Brushy Fork, which extended up tributary valleys and overtopped the lowest col. This outflow cut Black Hand Gorge. This and earlier interpretations relied principally on the regional topography and some assumptions about the extent of the ice sheets. Although it is certainly possible, and in fact probable, that some incision of the gorge took place during the Illinoian, the analysis of soils, sediments, and terrace stratigraphy strongly suggest a late Wisconsinan date for the reversal of the Licking River and final cutting of Licking County's most notable topographic feature.

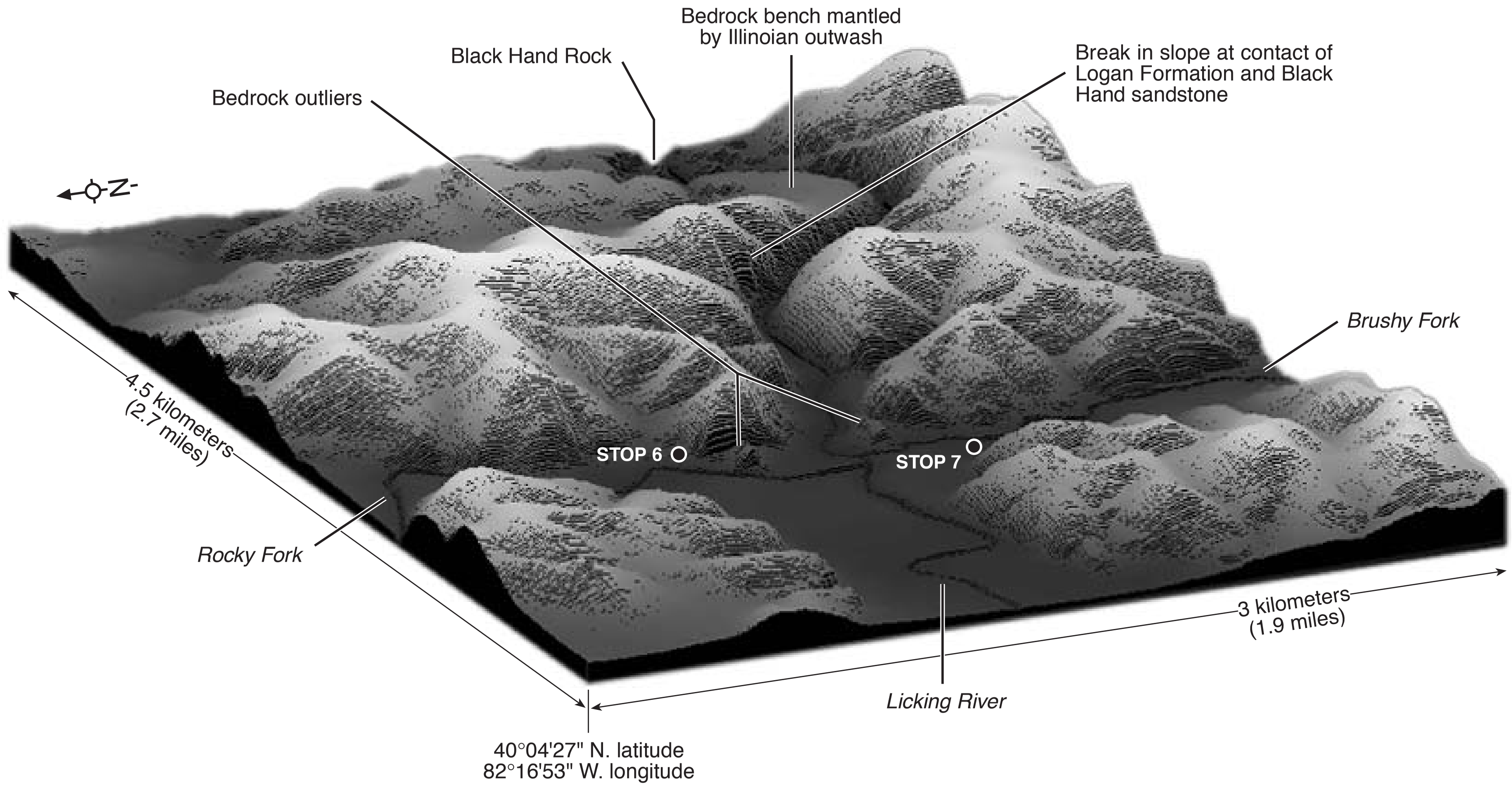

FIGURE 7.1.—Relief diagram of Black Hand Gorge and portions of the lower Licking River, Rocky Fork, and Brushy Fork valleys looking east-southeast. Elevation data taken from digital elevation model (DEM) of portions of the Hanover and Toboso quadrangles.Vertical exaggeration approximately 3:1.

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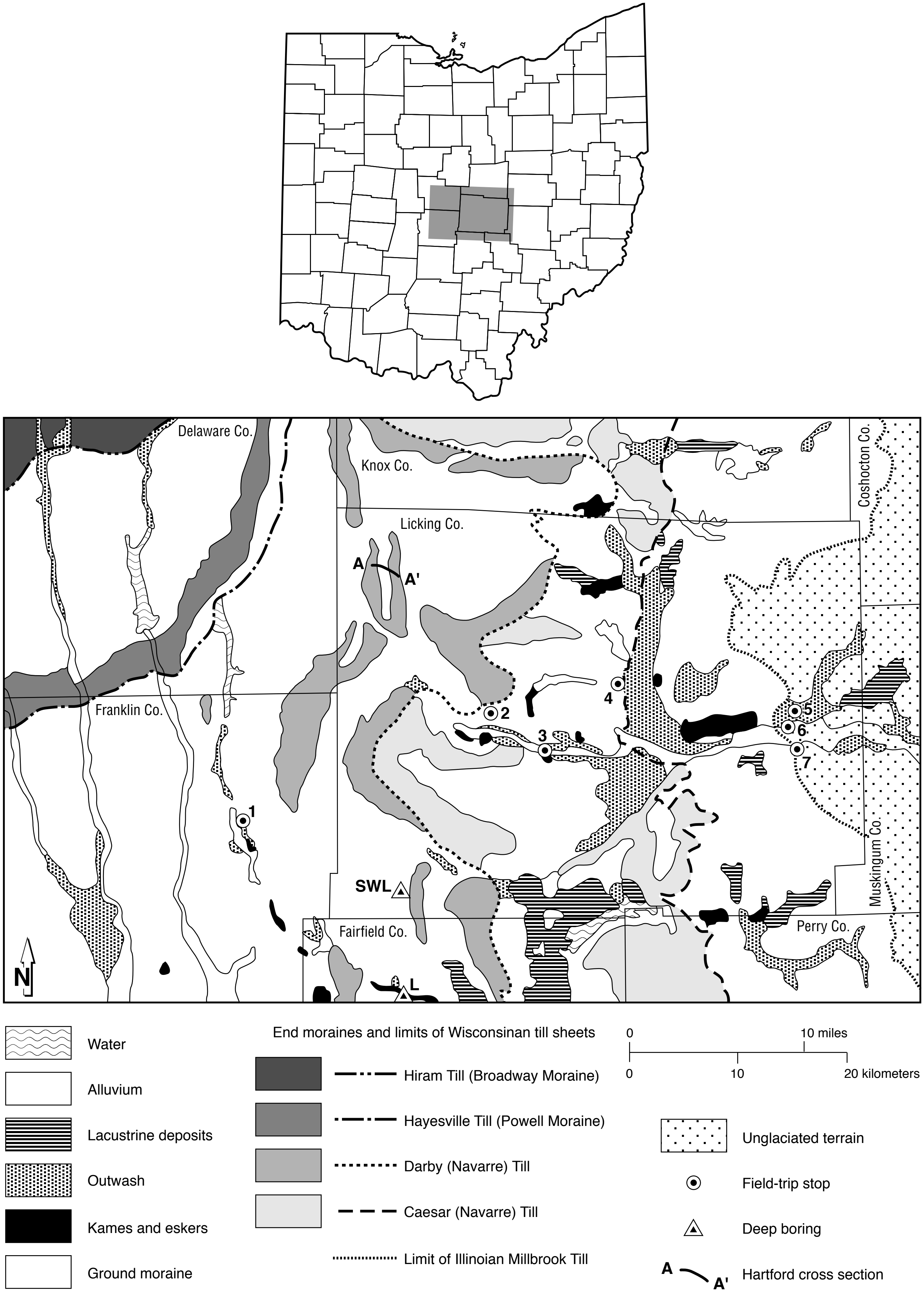

GENERALIZED MAP OF FIELD-TRIP AREA